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ANALYSIS OF ARMY OPERATIONAL REQUIREMENTS FOR THE TACTICAL MICROWAVE LANDING SYSTEM

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FINAL REPORT

by

P.G. Stoltz and J.H. Priedigkeit

NOVEMBER 1975

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FINAL REPORT

SRI Project 4462

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Prepared by

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A definitive set of test requirements are developed for the U.S. Army evaluation of the Microwave Landing System (MLS). The approach taken in to (1) access the Army operational requirements for an aircraft landing system in the 1980-1990 era, (2) compare the 1980-1990 operational requirements to the FAA Engineering requirements for the tactical MLS configuration, (3) recommend specific tests to

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CONTENTS

TABLES

FIGURES

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GLOSSARY OF TERMS

AAF	Army airfield
ACC	Army communication channel
ACCB	Air cavalry combat brigade
ADF	automatic direction finder
AHP	Army heliport
CONUS	continental United States
DH	decision height--the point in a precision approach, expressed in feet above the runway threshold, where a go-around or land decision must be made
DME	distance-measuring equipment
FAF	final-approach fix
IAF	initial-approach fix of an instrument approach
IFF	identification: friend or foe
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological condition
GCA	ground-controlled approach
GPS	global positioning system
LOS	line of sight
MDA	minimum decision altitude, see DH above
MLS	microwave landing system
NDB	nondirectional beacon--when navigating with ADF equipment

NOE	nap of the earth--very low level flying with visibility as low as 1/8 nm
OCONUS	outside continental United States
PAR	precision-approach radar--part of the GCA system
PIA	precision instrument approach
PLARS	position location and reporting system
RNAV	two-dimensional area navigation--routes may be selected independent of the location and ground facilities
SAS	stability augmentation system
VFR	visual flight rules (when applied to Army aviation tactical operations, flight performed with reference to visual clues--no legal minima apply)
VNAV	vertical navigation--an extension of two-dimensional area navigation
VOR	VHF omni range--a facility or navigation service
VORTAC	a combined facility or navigation service

EXECUTIVE SUMMARY

The objective of this study is to develop a definitive set of test requirements for the Army Microwave Landing System (MLS) evaluation. The approach taken is to (1) assess the Army operational requirements for an aircraft landing system during the 1980-1990 era, (2) compare the 1980-1990 operational requirements to the Engineering Requirements, FAA-ER-700-03, for the tactical MLS configuration, (3) recommend specific tests to be made by the Army during the MLS Phase-III evaluation of the tactical configuration, and (4) review five computer models for suitability to calculate MLS guidance accuracy in a multipath propagation environment.

The results of this analysis are as follows:

- It was concluded that the Army 1980-1990 operational requirements can be satisfied by tactical MLS equipment built to the engineering specifications stated in the Engineering Requirements, FAA-ER-700-03. The operational performance of the tactical MLS configuration at sites typical of brigade airfields and heliports and city heliports, however, is not defined in the Engineering Requirements. Depending on the multipath propagation environment, therefore, the operational performance at brigade airfields and heliports may be degraded below that at a site typical of a corps rear airfield.

- It is recommended that the tactical MLS configuration be flight tested by the Army in multipath conditions representative of Army tactical airfields and heliports to determine the deployment limitations.

- It is also recommended that the use of horizontal or circular signal polarization and control of the azimuth beamwidth of the elevation scanning beam be evaluated for effectiveness in reducing the multipath interference level.

- It was found that the engineering requirements for electronic security of the MLS tactical configuration need further definition because the threat and level of security are not defined. It is recommended, therefore, that deployment strategies be developed for the tactical MLS to minimize the threat to electronic security.

- It was concluded that the Lincoln Lab computer model for MLS multipath propagation studies is suitable for investigating the performance of the tactical MLS configuration in Army tactical environments; however, realistic descriptions of the multipath environment are lacking.

- It is recommended that the Lincoln Lab computer program be modified to include algorithms for horizontal and circular signal polarizations and for reflections from corrugated surfaces and that computer-model studies be made of the flight-test area used for the Army evaluation of the tactical MLS configuration.

I INTRODUCTION

The capability to land aircraft during periods of restricted visibility caused by fog, rain, or snow is a requirement of both the civil and military air fleets. Thus FAA and DOD are jointly sponsoring the development of a common microwave landing system (MLS) to meet the operational requirements of both the civil and military communities. This approach will be cost effective in that only one type of landing system will be necessary. In addition, with the use of a common signal format, military aircraft will be able to operate in the civil environment and, equally important, the civil reserve fleet can operate in the military environment during an emergency.

Performance specifications for the common MLS have been developed through the cooperative efforts of FAA, DOD, and industry. These specifications consider the spectrum of operational requirements represented by civil and military aviation. Currently, four civil and two military MLS configurations are being considered to meet these requirements. The military configurations are the Common Tactical and the Shipboard.

This report explores the U.S. Army operational requirements for an aircraft landing system during the 1980-1990 era and compares these requirements to the FAA-DOD performance specifications for the MLS common tactical configuration.* The object of the comparison is to identify discrepancies or omissions and to recommend specific operational tests to ensure that the Army operational requirements are met.

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* Federal Aviation Administration Engineering Requirements, FAA-ER-700-03, for the Army Microwave Landing System, 24 February 1975.

II OBJECTIVE AND SCOPE

The objective of this study is to develop a definitive set of test requirements for the Army Microwave Landing System evaluation. The approach taken is to (1) make a realistic assessment of the operational requirements of the U.S. Army for an aircraft landing system during the 1980-1990 era, (2) compare the 1980-1990 operational requirements to the Engineering Requirements, FAA-ER-700-03, for the MLS tactical configuration and to identify apparent discrepancies or omissions, and (3) recommend specific tests to be made during the evaluation of the MLS tactical configuration hardware to ensure that the projected 1980-1990 operational requirements of Army aviation are met.

The scope of this study considers Army aircraft operation in both peaceful and hostile environments in and outside the continental USA during 1980-1990 era. The size and mix of the Army air fleet are considered as is the impact of navigation systems and air traffic control procedures as the landing system requirements are estimated.

Because the Army will frequently operate from small obstructed airfields or heliports, multipath reflections of the landing guidance signals are of prime consideration. The scope of this study therefore includes a brief summary of available computer models to predict the performance of the MLS in a complex multipath environment.

III REVIEW OF REQUIRED OPERATIONAL CHARACTERISTICS FOR THE ARMY TACTICAL MLS CONFIGURATION

This section reviews the operational requirements as stated by the Army for the development of the common tactical MLS configuration. These requirements were submitted by the Army to the FAA in 1971 and were revised and resubmitted by the Director of Developments, U.S. Army,* in October 1973.

The FAA's Operational Considerations Panel issued a Position Paper, during the Phase II evaluation, describing the operational requirements for a common tactical system based on those submitted by the military service. This Position Paper, circulated for comment in October 1974, included a uniform rain model to facilitate the comparison of the rain performance of the civil "basic" and the "common tactical" MLS configurations. The operational requirements for a common tactical system, including the rain model, were approved by the FAA's Operational Considerations Panel in November 1974.

A recommended Army position on National Microwave Landing System (NMLS) was stated by the U.S. Army Training and Doctrine Command, TRADOC. This document† summarizes the physical environment in which the tactical MLS configuration will be expected to operate and contains the following direct quote:

> "The Army requires a landing system which consists of a ground station, capable of either split or collocated siting, and a compatible airborne set. The Army is required to operate aircraft from unimproved tactical landing areas and the system must provide reliable, positive guidance in this environment. Army landing areas are characterized by the presence of the following factors not normally present in civil aircraft operations; uneven, unprepared landing surface; proximity to obstacles such as trees, buildings, revetments and other structures, communications and the other types of antennas; high velocity rotor wash and dust blown by rotor wash; and numbers of moving aircraft in close proximity to the radiating elements. The Army system must interoperate with the Civil Microwave Landing System (MLS) and the MLS of the other military services."

---

* Letter from BG D. R. Keith, Director of Developments, to Administrator of FAA, ARD-700, 17 October 1973.

† Letter from LTC S. J. Azzarelli, TRADOC, Fort Monroe, Virginia, to HQDA (DMA-WSA), Washington, D.C. dated 3 February 1975.

This document makes it very clear that the Army landing areas are not the same as for civil aircraft and that the Army requires interoperability with both civil and other military landing systems.

The draft engineering requirements for the MLS Phase-III procurement of the common tactical configuration of the Microwave Landing System were issued by the FAA on 24 February 1975.

Table 1 is a comparison of the Army operational requirements, the operational requirements for the common tactical system, and the engineering requirements for the common tactical MLS configuration. It can be seen that the operational requirements stated by the Army are reflected in the engineering requirements for the tactical MLS configuration and, with a few exceptions, all the operational parameters specified by the Army have been met. These exceptions are not considered to be significant and are listed below.

- Low and normal modes of RF power levels is deleted.
- A decision height-warning indicator is deleted.
- The DME capacity is reduced from 100 to 50 aircraft.
- Reserving 30 MLS channels for the military is considered.
- Frangible antenna structures are deleted.
- The requirement for two installation personnel to be transported with the equipment is deleted.

Mission scenarios are not included in the Army operational requirements documents. However, the Engineering Requirements clearly state that the basic mission of the MLS tactical configuration will be to provide precision-approach guidance for CTOL, VTOL, and STOL aircraft in a military tactical environment; and further state that the split-site guidance accuracy shall not be degraded below that required for ICAO CAT-I on runways up to 7000 ft and for ICAO CAT-II on runways up to 4000 ft under the following conditions.

- Close proximity (10 ft) of the tactical MLS to objects below the horizontal plane tangent to the lowest radiation element of the guidance antenna.
- Placement of the angle-guidance elements near a body of smooth water.
- Placement of sandbags within 10° of the angular-sector coverage.
- Operation near natural hill formation, on one or both sides of the approach path, with and without foliage and snow coverage.
- Operation near man-made structures and equipment that satisfy the obstruction-clearance criteria.

Table 1

REQUIREMENTS FOR THE MLS TACTICAL CONFIGURATION

Operational Parameters	Army Operational Requirements*	Operational Requirements for Common Tactical System†	Engineering Requirement for MLS Common Tactical Confiuration‡
1. Interoperability with civil and other military landing systems	Required	Required	Required
2. Azimuth coverage	$\pm 30^{\circ}$ from centerline	$\pm 40^{\circ}$ from centerline	$\pm 40^{\circ}$, adjustable to $\pm 7.5^{\circ}$ in no larger than 2.5° increments
3. Elevation coverage	1° to 20° in elevation	Same	1° to 20° with lower limit adjustable from 1° to 6° in 0.5° increments
4. Minimum guidance altitude	50 ft	100-ft decision height for 4000-ft runway 200-ft decision height for 12,000-ft runway	150-ft minimum guidance altitude ICAO CAT-I conditions, 7000-ft runway 50-ft minimum guidance altitude ICAO CAT-II conditions, 7000-ft runway
5. Range	10 nm in 50 mm/hr rainfall	10 nm minimum (note 2)	At least 10 nm (note 2)
6. Set-up time	1 hr under worst-case climatic conditions with two men	15 min initial 3 min for reorientation	15 min set-up time
7. Site terrain	Slope to 10°	Same	Same

*1971

†October 1974

‡February 1975

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirement for MLS Common Tactical Configuration
8. Personnel skill	Unsophisticated	High school education and military training	High school education and military training
9. Complexity of installation equipment	Unsophisticated	No special tools	No special tools
10. DME azimuth coverage	Angle sector coverage required 360^{o} coverage to be considered	Same	Angular guidance service sector coverage required optional capability to select 360^{o} coverage desired
11. DME range	Same as angle guidance	20 nm (30 nm desirable)	At least 20 nm
12. DME accuracy	$\pm$100 ft	$\pm$ 100 ft	60 ft
13. DME capacity	Not specified	100 aircraft	50 aircraft
14. MLS configuration	"G" configuration based on 4000-ft runway (note 1)	Common tactical configuration	Common tactical configuration
15. Operational mode	Continuous or standby	In standby mode, the continuous mode can be activated by coded DME integration	Require a coded DME integration to activate angle guidance when in the demand mode

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
16. Power Source	Comparable with standard Army generators (28 v dc and 110 V 60 Hz) 2-hr operation from 28 V battery	Same	Same
17. RF power-level adjustment	Consideration for a low-power mode of operation	None	None
18. Monitor	Self-monitoring with automatic alarms when tolerances are exceeded	Same, with executive control to shut down equipment	Requirements for internal monitor with executive control and capacity to identify fault External monitor provided for optional use
19. Site configuration	Split or colocated azimuth and elevation	Same	Same
20. Size and weight of ground equipment	Size to fit UH-1/H helicopter cargo compartment with two installation personnel Weight-design goal with transit case, installation equipment, and batteries for 2 hr operation not to exceed 200 lb Single-component weight-design goal not to exceed 120 lb	Same - except the requirement for two installation personnel is deleted and a requirment to be man-transportable for short distances is added.	200 lb total maximum weight 120 lb maximum for one item 92 in. maximum length, 49 in. maximum height Man portable over a distance of 2500 ft

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
21. Glide-path guidance angle	Selectable in aircraft in 0.5^{o} increments over 2.5^{o} to 12.0^{o} range	Same	0.5^{o} increments from 2^{o} to 6^{o} and in 1^{o} increment from 6^{o} to 15^{o}
22. Azimuth guidance angle	Selectable in aircraft in 1^{o} increments over azimuth sector coverage	Same	Same
23. Decision-height warning	Indicator light, DH, can be preset by pilot	Deleted	None
24. Below minimum glide-path guidance warning	Automatic on three selectable azimuths	Warning to indicate selection of an unsafe glide slope	Same
25. Indicator sensitivities	Course softening in azimuth and elevation as courses converge near ground facility	None	Three-position course-width selector: AUTO for automatic course softening; FINE for no course softening; COARSE to reduce course sensitivity to 6^{o} azimuth sector
26. Aircraft antenna coverage	Omnidirectional for normal aircraft maneuvers	None	Antenna to have 360^{o} azimuth free-space coverage There is a requirement to provide for automatic or manual selection of more than one antenna to achieve 360^{o} coverage when installed on the aircraft

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
27. Airborne compatibility	Compatible with civil and other military, and "G" configuration of MLS except for DME	No specific requirement	No specific requirement
28. DME in aircraft	Optional		Separate receiver
29. Size and weight of airborne equipment	Size not to exceed: 10-7/8 in. width 19-3/16 in. deep 10-7/16 in. high Control unit not to exceed: 5-1/2 in. depth 3 in. height Weight: 20 lb maximum	Same	Size of guidance-angle receiver: 1/2 ATR reduced to 9 in. length DME interrogator/receiver: 4.85 x 7.00 x 9.00 in. Weight, including cables, should not exceed 25 lb
30. Power source	28 V dc aircraft power	Same	115 V 400 cycle or 28 V dc
31. Power consumption	To be minimized	Same	Consistent with state of the art

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
32. Reliability, availability, maintainability	MTBF of ground equipment 1000 hr MTBF of airborne equipment 1000 hr 98% probability of being restored to operable condition within 15 min by one man with high school cducation, technical maintenance training, and necessary tools, manuals, and spare parts immediately available Special tools are to be kept to a minimum	Samc	MTBF of ground cquipment not less than 1000 hr Maximum time to detect, remove, and check out major componcnts at organizational level not to exceed 10 min Mean corrective maintenance time not to exceed 15 min Maximum correction maintenance time not to exceed 45 min
33. Climatic condition	Worldwide	Worldwide	Design goal for production equipment is to operate with 1/2 in. of ice on all surfaces except antenna radome which can be manually cleared of icc
34. Wind	Nonc	Operational without accuracy degradation in a 45 MPH wind Structurally to withstand 100 MPH wind	To be functional in a 75 Kt wind and to withstand a 100 Kt wind without damage

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
35. System integrity	None	Compatible with national and ICAO standards	Internal, and optional external, monitors to ensure that erroneous guidance signals are not radiated for operationally significant periods.
36. Electronic warfare	None	Consideration to be given to one or more of such hostile actions as jamming, spoofing, detection and decoy, radiation-seeking weapons	Circuits incorporated to minimize guidance degradation caused by deliberate improper transmissions from sabotaging sources and to recognize the presence of interfering signals
37. Security	None	Secure service demand mode required	Secure service demand mode requiring one, or more, correctly coded DME interrogation to activate the angle-guidance transmitters
38. Channels reserved for military	None	Consideration of reserving 30 of the 200 available channels	None
39. Frangible structures	None	Required	None
40. Air traffic control interface	None	None	Required to interface with the remote command
41. Signal frequency	None	None	C-band 5068.0 to 5187.7 MHz

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
42. Signal Polarization	None	None	Vertical
43. Elevation guidance system error budget and accuracy	None	None	Bias: ground 0.024^{o}, airborne 0.010^{o}, total 0.026^{o} Noise: ground 0.018^{o}, airborne 0.018, total 0.026^{o} Environmental effects: 0.089^{o} Total path-following error: 0.096^{o}
44. Azimuth guidance system error budget and accuracy	None	None	Bias: ground 0.16^{o}, airborne 0.02^{o}, total 0.16^{o} Noise: ground 0.07^{o}, airborne 0.036^{o}, total 0.08^{o} Environmental effects: 0.22^{o} Total path-following error: 0.284^{o}
45. DME range accuracy	None	None	DME ground-equipment accuracy, excluding airborne equipment and environmental effects: bias 32 ft, noise 24 ft Airborne equipment accuracy: total airborne path-following error: 40 ft Total system error: 56.7 ft

Table 1 Continued

Operational Parameters	Army Operational Requirements	Operational Requirements for Common Tactical System	Engineering Requirements for MLS Common Tactical Configuration
46. Remote control of ground equipment	None	None	Required up to 3000 ft

Note 1. The MLS configurations were designated as: B, D, E, F, G, I and K depending on the service category. The designations have been changed to: expanded, basic wide and narrow, small community, shipboard, and common tactical.

Note 2. A usable MLS signal is to be received after penetrating five (5) nautical miles of rain falling at a rate of fifty (50) mm per hr plus rain falling at a rate of twenty five (25) mm per hr for the additional range.

The engineering requirements for the tactical MLS configuration are more definitive and include more operational parameters than do the operational requirements stated by the Army. Such important parameters as integrity, electronic warfare, security, guidance accuracy, and air traffic control interface appear in the Engineering Requirements but do not appear in the Army Operational Requirements.

From this review, it is concluded that the Army Requirements, have been fully considered in the development of the engineering requirements for the tactical MLS configuration. The Army has made it very clear that it requires the tactical MLS configuration to operate from unprepared landing areas in close proximity to obstacles such as trees, buildings, revetments, and other structures. Neither the Army nor the Engineering Requirements (FAA-ER-700-03) specifies the guidance accuracy for tactical environments such as brigade airfields and heliports or city heliports.

IV ARMY LANDING-SYSTEM REQUIREMENTS

The purpose of this chapter is to develop a perspective of Army aviation operations in the 1980-1990 era and to identify operational requirements peculiar to the landing of Army aircraft under instrument meteorological conditions (IMC).

The development of the common civil ATC system (upgraded third-generation system) will lead to a greater commonality between military and civil IMC operations. It will also necessitate the eventual acquisition of compatible avionics equipment by the military so as to operate in the civil airspace.

Army aviation planners are placing increased emphasis on attaining an improved IMC capability for the helicopter forces. This includes more IMC training expansion of the IMC avionics complement of aircraft, and plans for the transition from dependence on GCA for precision-approach guidance to a cockpit-oriented precision-approach capability employing ILS guidance signals in the near term and MLS guidance signals in the 1980s. Army aviation planners are also faced with the procurement of an instrument landing system to complement the increased emphasis on the use of Army aviation in night and foul-weather tactical operations.

The MLS in a tactical environment will satisfy the need for commonality between military and civil aircraft, will result in a savings in development costs, and will provide interoperability between the military services. As a result, the objective and first requirement for a tactical MLS configuration is interoperability with civil and other military services.

There are, however, other requirements that must be satisfied for Army tactical operations. These operational requirements will be identified in the following text whenever appropriate.

A. Army Airspace Structure in Wartime

Airspace service areas are illustrated in Figure 1* in which brigade, division, and corps areas are defined. The various lines (or boundaries) delineate airspace control and tactical interfaces. The forward edge of the battle area (FEBA) is the contact line with hostile forces, this line is usually ragged and indefinite. General outposts (GOP) and combat outposts (COP) extend into hostile areas. The fire-support control line (FSCL) represents the furthest reach of fire support and would be the limit of Army airspace control. If the extent of airspace

* References are listed at the end of this report.

services does not coincide with the FSCL, a forward airspace service line (FASL) would be established. The division rear boundary defines the rear area service line (RASL).

Behind the division rear, the Air Force component would usually have traffic control authority, whereas Army aviation ATC elements would control air traffic between the RASL and the FSCL up to a coordinating altitude established for the theater; at times, this coordinating altitude may be as low as 200 ft.* The Air Force would also control airspace above and forward of the Army airspace service area. Army ATC elements would have control of Army airfield terminal operations and would manage Army aviation flight plans. In effect, Army IFR traffic behind the RASL would be under Air Force ATC control unless delegated to Army authorities.

The most forward Army precision-approach instrumented (PAI) heliport would be located in the brigade rear. Additional dispersed VMC noninstrumented strips/heliports would complement the PAI airfield. A division rear main and alternate airfield would usually be deployed. Other PAI airfields and heliports would be found in the corp rear and COMMZ areas. All of the PAI landing-field terminal airspaces would be connected by IFR air routes. The flexibility of IFR navigation and air-route structure existing in the 1980-1990 time frame would depend on the available navigation techniques. Some form of area-navigation service would expedite the structuring of IAFs and FAFs for feeding traffic into MLS coverage.

In the Air Force traffic-control areas, IFR traffic should fly at en-route altitudes under surveillance by radar/beacon/IFF systems; generally IFR minimum en-route altitudes would be more than 1000 ft above the highest terrain along the air-route path. Large rear-area Army airfield operations would have radar/beacon surveillance, thereby providing appropriate sequencing of arriving and departing IFR aircraft. Most Army VFR flight activity would be conducted below the Air Force controlled airspace in the rear area. The Army component authority, such as the corps flight organization center (FOC), may be delegated jurisdiction of the low-altitude en-route airspace.

- Requirements

  An interface with air traffic control and with the area navigation system is required.

  The tactical MLS must be deployed at heliports and airfields in the corps forward area, specifically the brigade and division rear airports.

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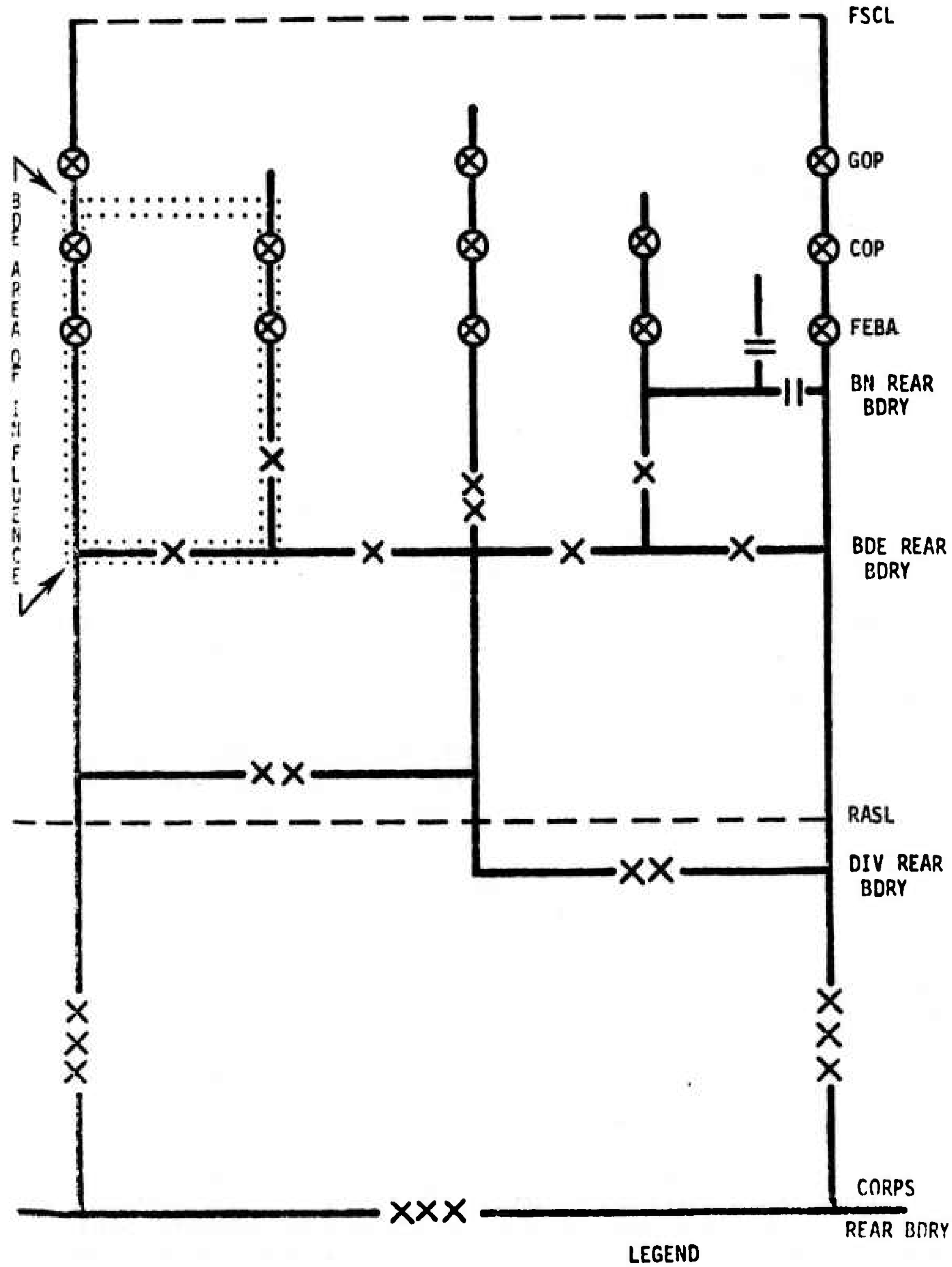
* Discussions with Ft. Rucker personnel.



Schematic-NOT TO SCALE

SOURCE: CDA Airspace Service Plan.

SA-4462-1

FIGURE 1 AIRSPACE SERVICE AREAS (Ground)

B. Aircraft Mission and Flight Profiles

1. Threat

Aircraft mission profiles in the forward areas of the tactical theater must accommodate to the enemy air-defense threat for survival This threat consists of such weapons as:[2]

- Rapid-fire air-defense gun weapons (23 nm ZSU 23-4 self-propelled antiaircraft system)
- SA-7 man-packed IR homing-missile system
- Various automatic weapons employed by ground forces
- Fixed-wing tactical aircraft and armed helicopters
- All-weather radar-directed air-defense weapons

Army aircraft must remain below the enemy radar and optical horizon to minimize exposure to hostile weapons. This survival consideration dictates a flight profile as shown in Figure 2. Because low-altitude nap-of-the-earth (NOE) flight techniques[3] must be used in the forward combat area, there is no requirement for the deployment of a landing system in this area.

Aircraft operating in the division rear and corps rear airspace have more freedom to fly at higher altitudes to avoid terrain and to operate at higher airspeeds. Landing systems will be deployed in these rear areas.

2. IFR Mission Profiles

It is expected that tactical IFR flight profiles in the rear area would be similar to peacetime flight profiles. When near the forward area, the lowest safe en route flight levels will be flown. Air traffic control and spacing criteria probably would be sufficient to ensure the level of safety required for the larger transport helicopters that would be operating typically in the rear area. In wartime, established IFR minima would be lowered to meet tactical needs.

IFR missions would be flown in rear areas up to the brigade rear airfields.[5] When weather conditions permit, VFR flight would be conducted in the lower part of en route airspace and probably would be the preferred mode of operation. VFR landing rates for helicopters are

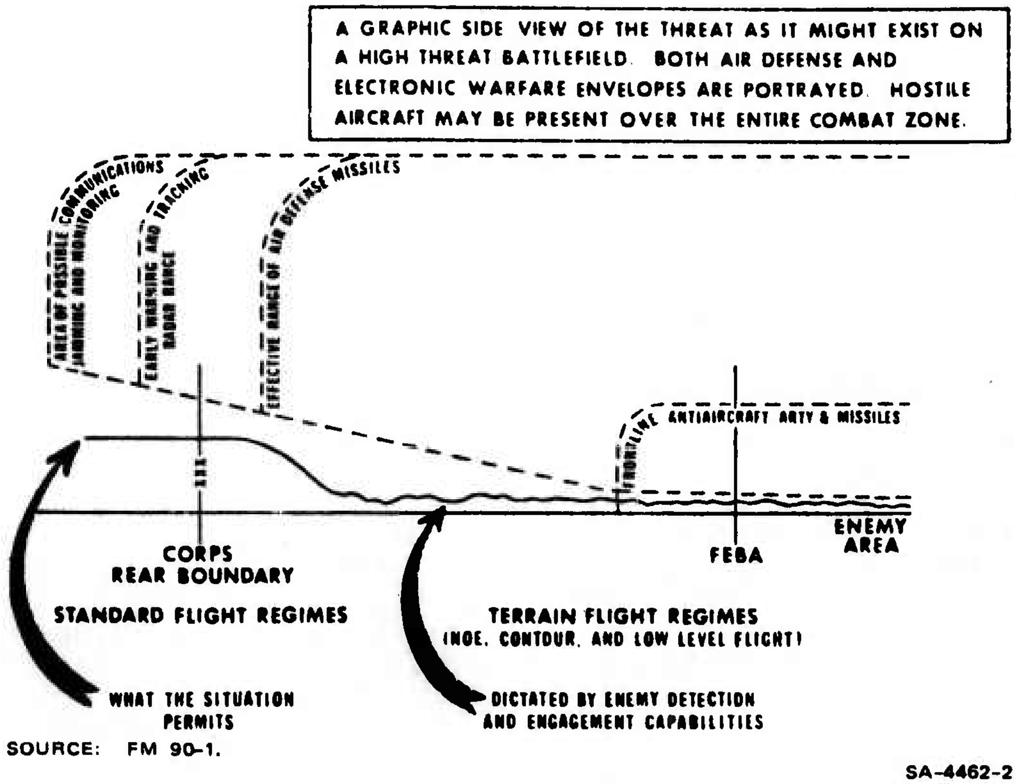


FIGURE 2 THREAT PROFILE

expected to be much higher than IFR landing rates. Mission types by IFR and VFR* conditions are listed in Table 2.

A typical IFR/VFR mission is illustrated in Figure 3. Note that IFR operational altitudes are quite low in the division area. The final part of the mission is conducted visually.†

- Requirement

  The tactical MLS would be required to provide IFR approach-to-land and let-down service. Let down service probably would be the dominant service demand in view of the capability of helicopters to conduct visual flight activity in IMC weather down to 1/8 nm visibility.

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* IFR flight implies flying by means of instruments; VFR flight implies flying by means of outside-of-cockpit visual cues.

† Visual flight may occur down to an IMC of 1/8 nm, a visibility level usually associated with a CAT III-A type of instrument approach; therefore, VMC and IMC lack definition in the Army tactical environment.

Table 2

MISSION TYPES

Mission	IFR	VFR	Comments
Logistics (rear airfield to forward airfield)	x	x	
Logistics rear airfield to forward area point		x	VFR in destination area
Medical evacuation	x	x	VFR on initial pickup
Reconnaissance	x	x	IFR for ELINT
Armed escort		x	
Armor attack		x	
Fire suppression		x	
Troop transport	x	x	VFR if landing near FEBA
Night mission	x	x	IFR recovery more desirable
Forward area rearm/ refuel	x	x	IFR approaches for 1st down to VFR conditions

FLT. PROFILE FROM CORPS REAR TO FWD UNIT IN BRIGADE (ASSIGNED ALTITUDES ARE BASED ON THREAT CONSIDERATIONS AND TERRAIN CLEARANCE AS WELL AS AIRCRAFT SEPARATION)

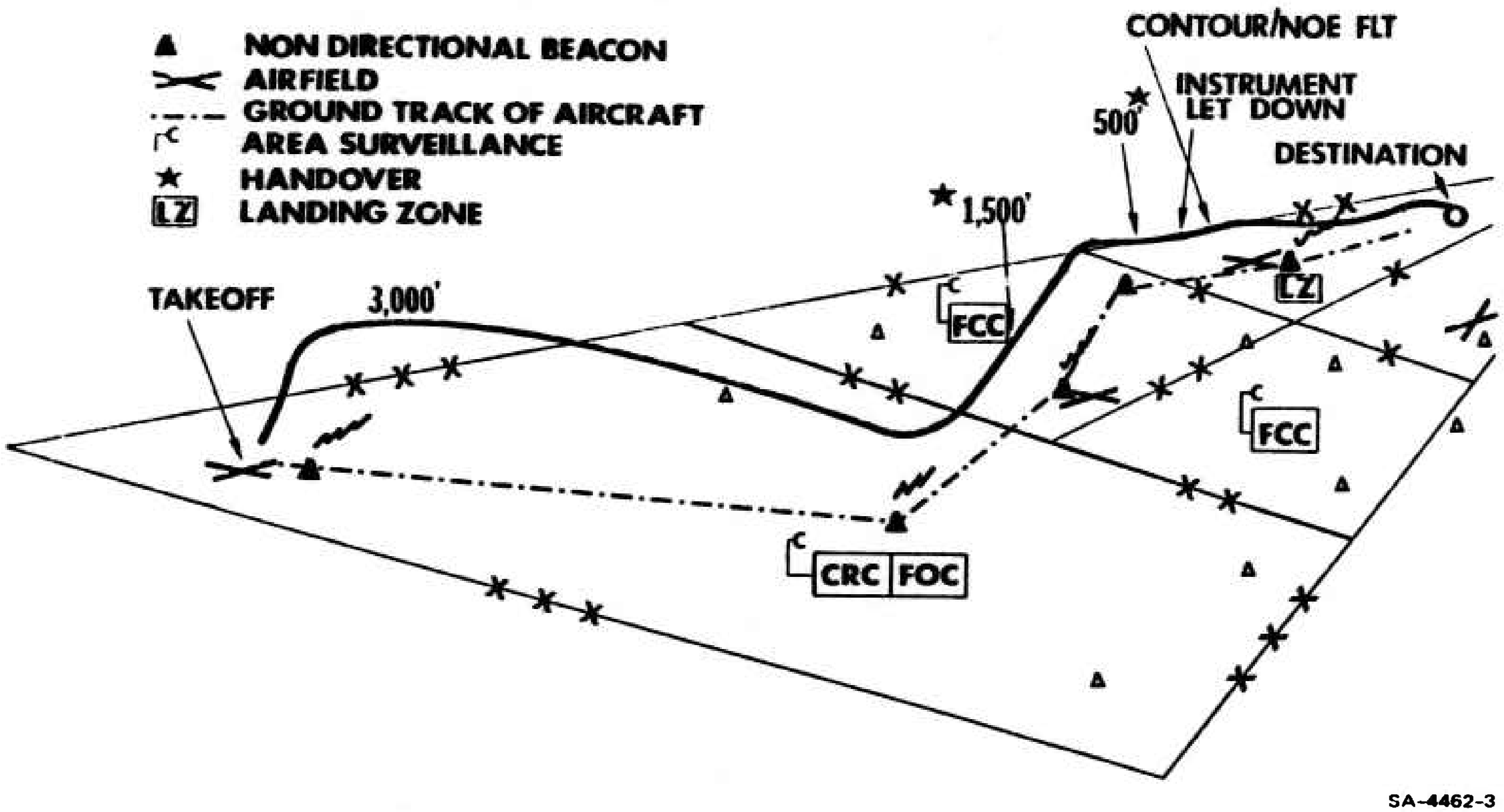

FIGURE 3 TYPICAL ARMY TACTICAL FLIGHT PROFILE

C. Army Air-Fleet Composition (1980-1990)

The Army air fleet is being consolidated, and standardization is being focused on relatively few types of aircraft. Fixed-wing aircraft are the minority and represent approximately 10 percent of the 9000 aircraft of the current Army fleet. The size of the fleet and mix of fixed- and rotary-wing aircraft are not expected to change materially during the 1980-1990 period. Table 3 lists the types of aircraft expected during the early 1980s.

At present, fixed-wing aircraft are limited to models of the Mohawk and the Beech U-21 series. It is understood that all Mohawks are being upgraded to the D-version. A number of different models of the U-21 Beech twin-engine turboprop are in operation; the latest version is the T-tail or King Air-200 type of aircraft. Future fixed-wing options are categorized as the Ux, a twin engine utility aircraft and a twin-engined STOL aircraft.

The current helicopter fleet consists of a large number of utility transport types and a growing number of attack types, each grossing 10,000 lb or more. The Chinook will remain the heavy transport helicopter for the foreseeable future because the HLH program has been canceled. The UTTAS is destined to become the backbone light transport helicopter. Both competing contractor models of the UTTAS will be equipped with flight directors. The other advanced helicopter in the prototype stage is the AAH; competitors are Bell and Hughes. It is believed that these helicopters will also have a flight director and that they may become the ultimate replacement for the Cobra series. An advanced scout helicopter (ASH) replacement for the OH-58 is expected within the latter half of the 1970s.

Older helicopters to be retained in inventory are likely to be upgraded with respect to IFR capability, flight performance, and weaponry; however, a comprehensive IFR capability-upgrading program is not evident. As a result, it is not expected that all Army helicopters will acquire flight directors by the mid-1980s or other IFR equipment refinements. Most helicopters probably will be equipped with the MLS DME and angle-guidance receivers. Aircraft without the optional DME receiver would have limited flexibility to operate within the full coverage of the MLS.

The Air Cavalry Combat Brigades (ACCB) concept is being developed by Army aviation;* the first is being organized at Ft. Hood, Texas. Nap-of-the-earth and low-level night-flying training is stressed, and

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* "New Helicopter Combat Roles Planned," AW&ST, 29 September 1975.

Table 3

AIRCRAFT CHARACTERISTICS

Aircraft	Mission	Notes
Fixed Wing		
Mohawk OV-1/D	Special missions, reconnaissance	Well equipped for IFR
Beech twin-engine U-21 turboprops (pressurized)	Special missions, utility	Well equipped for IFR
UX		Twin-engine utility aircraft
U-( )		Twin-engine STOL aircraft
Helicopter		
Cobra AH-1G, Q, R S	Armed escort and direct fire support, TOW launching	GW:9500 to 10,000 lb, single engine
Iroquois HU-1H	Troop transport, command and control, medevac	GW:9500 lb; crew of two, 11 passengers, single engine (Marine J-version has two engines)
Chinook CH-47 A-C	Transport (personnel and cargo), downed aircraft recovery	GW:46,000 lb, two engines
Tarhe CH-45 A,B	Heavy lift helicopter	Out of service
Yah-63 -64 AAH	Attack helicopter--night and adverse weather operations	Two engines (GE T700) Bell/Hughes competition. Projected to have FD and limited SAS.
OH-58 ASM (interim)	Aerial scout	
YUH-60 UTTAS -61	Troop transport (11 troops)	Two engines (GE T700) Boeing/Sikovsky competition, production in 1979 has FD and limited SAS
HLH	Extended transport of heavy or bulky cargo	Canceled

Source: AW&ST, 17 March 1975

the aircraft and pilots will have instrument flying capability. The streamlined ACCB of 1976 includes:

- 138 AH-1Qs assigned to the attack helicopter battalion (63 aircraft/squadron)
- 15 AH-1Gs assigned to the air-cavalry squadron
- 106 Bell OH-58 scout helicopters (some assigned to the air-cavalry squadron and some to the attack battalion)
- 16 CH-47Cs assigned to the support battalion
- 61 UH-1Hs assigned to the air-cavalry squadron and to the headquarters and headquarters company.

If increased emphasis is placed on ACCBs and air mobile division, the size of the Army air fleet could increase considerably over that projected earlier.

- Requirement

  Deployment of precision-approach landing systems to handle the expected increased level of IFR flight activity during the 1980-1990 decade in both peaceful and hostile situations.

D. Volumetric Coverage of the Landing System

Current Army fixed-wing and helicopter aircraft operate with approximately 100 kt approach speeds. The newer aircraft are expected to operate near this speed, or lower for STOL aircraft or helicopters making a high-angle approach. A straight-in approach at 100 kt from a distance of approximately 4.0 nm allows approximately 2.5 min to maneuver the aircraft before touch down. This should be more than sufficient time for an experienced pilot to stabilize the aircraft for final approach. Allowing ± 1.0 nm uncertainty for the navigation system to locate the airfield or heliport requires the operational range of the landing system to be 5 nm.

In the corps forward area, air operations must be conducted at altitudes as low as possible to avoid hostile air-defense activity (see Figure 2). As a result, intercept of the 6° glide slope at a 4 nm range would take place at an altitude of approximately 2600 ft -- certainly too high an altitude at a brigade rear airfield in a high-threat environment. Fort Rucker personnel note that final approach paths can be shortened to approximately 2 n , particularly for the more agile attack helicopters.

Extended volumetric coverage will provide the pilot with the opportunity to perform selected azimuth-angle and curved approaches. Because these latter approaches require navigation guidance along paths other than those defined by raw MLS azimuth and elevation-angle data, the aircraft must be equipped with an MLS computer for curved-approach navigation within MLS coverage. The wide-angle coverage provided by the MLS can be tactically useful for high-minima let-down operations, as discussed in Section F.

Glide-path angles for helicopters are commonly 6° to 12°. For fixed-wing aircraft, they are 3°.

- Requirements

  A slant range of at least 5 nm for conventional straight-in approaches.

  An azimuth sector coverage of $\pm 40^{\circ}$ for helicopter let-down procedures.

  A vertical-angle coverage of 2° to 15° to accommodate both fixed-wing and helicopter aircraft.

E. Army Airfields and Heliports

This section describes three tactical situations in which the Army can be expected to deploy the tactical MLS configuration. The purpose is to define the physical environment and to identify operational requirements.

1. Rear Corps Airfield

This airfield would be located in a supply area on relatively level terrain. A landing strip would be approximately 4000 ft long and would support medium transports such as the C-130 and the AMST. Extensive ramp areas would be available for the loading and unloading of Air Force fixed-wing cargo aircraft and Army heavy helicopters such as the CH-47C.

The landing system would be deployed in a split-site configuration, with an approach landing-lights system, to provide the equivalent of ICAO CAT-II service to a 100 ft decision height. Ground-based enemy air defense would not be a threat in this area although occasional airborne attacks may take place. Terminal air operations and final approach-path sequencing would be similar to a civil operation. Air traffic would be directed by radar traffic control aided by beacon tracking. VMC weather helicopter operations would be expedited by visual-approach procedures, whereas large fixed-wing traffic would use the precision-approach landing system.

Many large helicopters and fixed-wing transport aircraft could be parked relatively close to the runway, thereby potentially causing a multipath problem for landing-guidance signals; otherwise, terrain and building constraints would be minimum for this typical corps-area installation.

- Requirements

  The MLS tactical configuration must be capable of providing the equivalent of ICAO CAT-II service to a 100 ft decision height, with a 4000 ft runway, in a physical environment similar to that of a civil airport.

  Minimal interference from aircraft parked or taxiing near the azimuth and elevation guidance-signal transmitters.

  Although not a part of the tactical MLS equipment, a landing-light system is required to support a 100 ft decision height.

2. Brigade Rear Airfield

This airfield would be located at the rear of a brigade area, and it would be the operational base for a large number of tactical helicopters performing primarily low-altitude VFR missions. The runway would be approximately 2000 ft long, with dispersed ramp areas for various types of helicopters. Revetments would protect most of the helicopters while on the ground. A split-site tactical MLS would be deployed and would be the most forward landing system in the combat area. Fixed-wing aircraft would also use this airfield for logistic missions.

An example airfield would be located in a relatively narrow valley with tree-covered low hills lying between the airfield and hostile area. The coverage of the service volume would be limited to $\pm 10^{\circ}$ in azimuth. A straight-in approach would sustain approximately a 20° angle with respect to the FEBA. As a result, MLS coverage would point slightly toward the division rear, and the 2 nm final-approach fix would be located further to the rear than the airfield. Because the final-approach path lies below the enemy radar horizon for the particular tactical situation, the aircraft on final approach are protected from the enemy ground threat.

The principal users of this landing facility would be missions coming from the corps area forward to the brigade area and some IFR missions within the brigade area. The field will have a tactical lighting system; however, CAT-II approaches would not be conducted except in an emergency. Aircraft returning from missions forward of the brigade area will not normally use the landing facility because they will approach from a low altitude to avoid enemy fire and would return to base employing low-level, contour, and NOE flight techniques.

- **Requirements**

  The tactical MLS configuration at brigade level will have to operate at airfields with nearby trees and located in narrow valleys. There will be revetments to protect aircraft, sandbags or a revetment to protect the landing-system electronics, and various types of helicopters on the ramp area adjacent to the runway.

  The angle-guidance service sector will be restricted to as narrow an angle as feasible to deny the enemy access to the guidance signal and to reduce multipath reflections from the nearby hills.

3. Hospital Heliports

A rapid transport of wounded soldiers to hospitals is an important function performed by Army medevac missions.

The heliport would be located adjacent to a civilian hospital in the downtown section of a city, as in Central Europe, and close to the division rear. It would be located in a small park or plaza near the hospital. Buildings and trees would set the approach angle at 8° for obstruction clearance.

Flight activity would be expected day or night and in any weather. Terminal traffic-control service would be available from a division rear airport. These traffic controllers would vector IMC helicopters medevac missions to the final approach path to the heliport. Coordination with the local controller at the heliport would be provided.

A close-split site configuration* would be used. The azimuth sector coverage could be restricted to as little as $\pm 10^{\circ}$, and the elevation coverage would not go below 6° to minimize multipath interference from buildings.

- **Requirement**

  A close-split site tactical MLS configuration must operate on a small heliport in a downtown city environment. Azimuth and elevation sector coverage would be restricted for obstruction clearance and to minimize multipath interference.

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* A very short runway with the azimuth guidance equipment located at the stop end and the elevation guidance equipment (GPIP) located at mid length.

F. Climatic Environment

Army tactical operations must be feasible in any geographic location. The tactical MLS will be expected, therefore, to operate in rain, snow, ice, high humidity and temperature, and blowing sand.

Rain will attenuate the MLS guidance signal and reduce the effective range. To ensure that the tactical MLS will operate anywhere in the world, the equipment should be designed to function in areas of heavy rainfall, such as Burma or Miami. Measured rainfall data indicate that the probability of the rainfall exceeding 2 in./hr over a 1 min period is less than 0.1 percent.

- Requirement

  The tactical MLS is required to operate in worldwide climatic conditions and in a rainfall intensity of 2 in./hr over one-half of the approach path.

G. System Capacity

The landing rate of an IMC airfield is determined by runway capacity, aircraft separation required to minimize collision, and aircraft capacity of the landing-guidance system.

Most Army airfields will have only one runway. As a result, for fixed-wing aircraft, the runway occupancy (for either landing or take off) will limit the landing rate to less than 2 aircraft/min.

Helicopters need not contact the runway for decceleration or use the runway to accelerate for takeoff; they may proceed directly to the parking area, revetment, or to another destination when visual contact with the ground is established. The landing rate for helicopters is determined, therefore, by consideration of separation to minimize collision in the terminal area. Helicopter separation would be achieved by spacing the aircraft on a specific approach radial of the azimuth guidance facility and by using more than one radial.

Assuming a one-mile separation between aircraft with a 100 kt approach speed, the landing rate for one radial is less than 2 aircraft/min.* When more than one approach radial is used, the angle between radials for a

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* This is a closer spacing than the typical 3 nm civil spacing but is assumed for tactical operations.

specified minimum horizontal separation of the aircraft can be approximated as

$$\theta = \frac{SL}{h} \qquad \text{(degrees)}$$

where

S = horizontal separation (in feet)

L = glide-slope angle (in degrees)

h = aircraft altitude (in feet)

The azimuth-angle separation required for a one-mile minimum horizontal separation with a 500 ft ceiling and a 3° glide slope is 36°. Three approach radials could be accommodated with a $\pm 40^\circ$ azimuth sector coverage under these conditions, and the landing (or let-down) rate would be increased from less than two to less than six aircraft per minute. A ceiling height of 250 ft would limit the number of approach paths to two. If higher glide-slope angles are used, ceilings must be higher or the minimum horizontal spacing should be reduced to achieve the same let-down capacity. To maintain spacing, air traffic control would be responsible for assigning flight radials and clearing aircraft for approach.

It is concluded that the landing rate is limited by runway capacity and aircraft separation considerations and not by the tactical MLS capacity.

- Requirement

  The Army tactical MLS configuration shall not limit the aircraft landing rate.

H. Autocoupled Approach, Autohover, and Autoland

It is understood that very few Army fixed-wing aircraft have three-axis autopilot systems, or an ILS/MLS autocoupled approach capability. There is no indication,* however, that there is a specific operational demand for such features as flight directors (FD), SAS, or autocoupled, autohover, or autoland systems for helicopters, particularly the attack types. Future aircraft such as the AAH and UTTAS will have some advanced instrumentation such as a flight director

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* Discussions with Ft. Rucker personnel.

and a limited SAS. There is no operational requirement for the helicopter autocoupled approach, autohover, or autoland.

I. Spectrum Utilization and Channels Required

The spectrum allocation for the MLS has been established for angle guidance and DME channels. Although it has been recommended that 30 channels of service should be set aside for military operations,* Army airborne units must have a full-channel capability because the aircraft should be able to fly into civil airfields. Tactical MLS ground systems should not be limited to the 30 channels but should have full tuning capability because operation on civil channels may be required in some tactical or emergency situations.

- **Requirement**

  A full 200-channel capability for the ground and airborne tactical MLS units to ensure interoperability with civil airports.

J. DME Capacity

The DME transponder will be interrogated by all aircraft that have selected a particular MLS channel and are within the service coverage of the DME. This includes aircraft that intend to use the landing facility plus those en route.

The number of aircraft in the service volume that can use the landing facility can be approximated by

$$\text{No. of aircraft} \cong \frac{R(lr)}{v} \times 60$$

where

R = service-volume range

v = aircraft speed

lr = landing rate

Assuming a service-volume range of 10 miles, an average speed of 100 kt in the service volume, and a maximum landing rate of 3 aircraft/min, the number of aircraft using the DME transponder for landing becomes

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* Operational Considerations Panel, Position Paper, 31 October 1974.

$$\frac{10 \times 3}{100} \times 60 \text{ or } 18$$

It is reasonable to assume that 15 aircraft are holding to land and that 15 are passing through the DME service volume en route to another destination. As a result, the DME capacity must be capable of handling at least 50 aircraft.*

- Requirement

  The DME capacity should not be less than 50 aircraft to accommodate the maximum landing rate of a single Army airfield and to allow a 30 percent reserve capacity for en route aircraft using the DME facility.

K. System Integrity

The angular guidance and DME signals radiated from the tactical landing facility must be monitored to ensure that the signals are within specifications and that potentially hazardous guidance signals are not radiated. The monitor should have executive control over the landing facility, should automatically turn off the guidance signals if a potentially hazardous signal condition is detected, and should alert maintenance support.

L. Signal Security

Examination of the signal format and the intended operation of MLS indicates little resistance to signal detectability and ECM. Should MLS become the ICAO standard, the channel frequencies and signal format will be available. Successive interrogation probing of all 200 DME channels by a hostile ELINT unit could locate, by DF techniques, an MLS facility and turn on the angle guidance and identification functions.

The angle guidance uplink can be jammed or captured at the discretion of a hostile ground-based or airborne ECM unit. An LOS relationship to the aircraft being jammed must exist for the ECM activity to be effective.

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* The characteristics of the DME system is such that the sensitivity of the receiver in the DME transponder is reduced as the transponder approaches saturation. This discriminates against the weak signals from distant aircraft and favors the strong signals from aircraft close to the airfield.

Measures to limit ECM success would include:

- Limit power radiated to minimize detectability of ground-radiated signals and exploitation of radiated signals for homing sources.
- Limit azimuth and elevation coverage, and direct DME and angle-guidance energy away from hostile territory (display low sidelobes to the enemy).
- Employ directive receiving antennas on aircraft to increase signal/jamming ratios of desired signals.
- Use other means to navigate to the FAF, and only use MLS for a short final approach path.
- Operate airfield in defilade to limit LOS ECM opportunities to the enemy.
- Maintain ECM surveillance on MLS channel and radar surveillance on aircraft making approach to prevent successful spoofing.

These measures would be applicable when operating close to hostile areas. In the rear area, the full services of MLS can be exploited.

- Requirement

  Security is an operational requirement of the tactical MLS; however, the threat has not been defined and the level of resistance to the threat has not been established for the MLS. Measures can be taken, as described, to minimize ELINT and ECM opportunities to hostile forces without altering the signal format and system signal processing.

M. Logistics

1. Mobility

Mobility is a prime requirement for Army tactical operations. Because the ground facilities must be highly mobile to take advantage of rapidly changing combat situations, tactical aircraft landing systems must be designed so that they can be transported, set up, and activated with a minimum of manpower and equipment. Equally important, the packaging of the tactical landing system should be designed so that it can be quickly disassembled and readied for transport to a new location. This may preclude the use of special packing cases and installation tools that are apt to be discarded or lost after the equipment is set up.

- Requirement

The construction of the tactical landing system must be modular so that it can fit in to Army aircraft, with installation personnel, for air transport and that it can be man-transported for loading and unloading.

The tactical MLS equipment should be designed to operate from any of the commonly acceptable power sources. (28 V dc or 115-220 V ac, 50 to 60 Hz or 380 to 420 Hz)

2. Maintenance and Support

A mean time between failures (MTBF) of at least 1000 hr in a military combat environment is required to ensure the operational reliability of the tactical MLS configuration.

During periods of hostility, the MLS will be maintained and supported in a combat environment; therefore, this equipment must be designed so that it can be maintained and serviced by minimum-skill personnel without the need for special tools or test equipment. Because equipment repair in brigade areas will be limited to the replacement of only the most readily accessible modules or line-replaceable units (LRU), built-in test equipment (BITE) or diagnostics to indicate the faulted line-replaceable unit is required. Spare LRUs will be held in supply at the rear corps area and dispatched as needed; a small supply of these units will be assigned to the equipment. Faulty LRUs will be returned to the rear corps area for repair or, depending on their cost, discarded as expendable.*

The mobility of the tactical MLS equipment will be utilized to replace a complete landing system from the rear corps area in the event of extensive failure or damage.

N. System Interfaces

1. Operational Control

The ground components of the MLS tactical configuration will be under the control of airfield-operations personnel who will be located several thousand feet from the azimuth and elevation guidance equipment.

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* The decision to repair or discard line-replaceable units should be determined by a cost analysis based on the production design of the tactical MLS configuration.

- **Requirement**

  A remote-control interface of the ground equipment is required to facilitate air traffic control operations.

2. Navigation Service

The aircraft pilot must rely on a navigation system to locate approach fixes within the service area of the landing system. The volumetric coverage requirements for the landing system are related, in part, to the expected accuracy of the navigation system; in section C, it was assumed that the navigation-system accuracy is ± 1 nm. With a less accurate navigation system, it may be necessary for the pilot to circle (DME orbit) the airfield to utilize effectively the performance characteristics of the landing system.*

Army aviation has relied upon the combination of ground-based NDBs and ADF-equipped aircraft for tactical navigation.† VOR navigation is satisfactory when flight altitudes are high enough to be within line of sight (LOS) of VOR facilities.

LORAN-C and doppler navigation-system approaches have been considered by Army planners. Fort Rucker aviation personnel, however, are concerned with the physical and ECM vulnerability of LORAN-C and it appears that LORAN-C will be dropped by the Army. The radiation of doppler signals also appears to be undesirable. Furthermore, doppler navigation is dependent on frequent updates and the use of a precise heading reference to obtain high accuracy.

Several new types of navigation sensors and systems are being developed by the Services. The laser ring gyros being developed by the Navy could eventually become the sensors for inertial systems for Army aviation if costs are found to be much less than those for current inertial sensors. The position location and reporting system (PLARS) is being developed by the Marine Corps. The global positioning system (GPS), also known as Navstar, is a global satellite-oriented position location and navigation system being developed by the DOD Joint Program Office to provide all Services with navigation.

A laser ring gyro inertial system, if it achieves accuracies comparable to current state-of-the-art inertial systems, would have a drift of 1 nm/hr without update. With timely updates, accuracies of approximately 1000 ft (1σ) could be operationally achieved. Although

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* Assuming that volumetric DME coverage is available. DME coverage may be operationally variable from a sector corresponding to azimuth coverage to full 360° coverage.

† Discussions with Ft. Rucker and Ft. Huachuca personnel.

primarily a reporting system, PLARS can provide navigation for suitably instrumented aircraft; accuracies of several hundred feet (1 σ) are estimated.

Discussions with Army aviation personnel* indicated much interest in the GPS. It is claimed† that GPS would provide 10 ft (1 σ) XYZ accuracy and precise time if signals are received from four or more satellites in view. The attractiveness of GPS is that it is not LOS-limited, requires no radiations from the user aircraft, and its signals are believed to be relatively secure.

The Army has the DOD responsibility for defining user equipment because it ultimately would be the largest user of GPS service. Current program schedules indicate some operational capability in 1982.

GPS would provide Army aviation with a highly accurate VNAV capability that would significantly enhance NOE operations. It would also enable IFR aircraft to navigate at lower altitudes with a precision not possible with current en route navigation techniques.

With GPS, aircraft would not need MLS signals at the full service coverage of MLS. The GPS area-navigation capability would enable pilots to fly complex approach paths to the MLS FAF. The transition between MLS and GPS can be a few miles from the runway at a selected azimuth approach path. GPS would also provide a three-dimensional non-precision approach at orbitrarily defined locations and thus facilitate high minima (MDA of $\approx$ 500 ft).

GPS will provide the aircraft flexibility to navigate within defined airspace boundaries (such as fire zones) and will provide army aviation with a greater navigation flexibility than now exists.

VORTAC RNAV service is to be time-phase implemented in CONUS in the 1980s. Implementation plans‡ call for the availability of three-dimensional profiles in the en route low-altitude airspace and the establishment of two-dimensional RNAV at high and medium density terminals for the 1982 System. Terminal air-route widths would be $\pm$1.5 nm. Because waypoints are defined by latitude-longitude and UTM Grid coordinates, inertial systems as well as navigation systems using radio signals other than VORTAC can navigate in RNAV airspace if the accuracy requirements are met. As a result, GPS navigation systems employing lat-long coordinates can operate in the RNAV/VNAV environments of the 1980s. Tactical navigation units could employ a common tactical grid system for a theater, such as the UTM grid.

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* Col. Dan Leonard, Pentagon and Ft. Rucker personnel.

† "New Space Navigation Satellite Planned," AW&ST, 15 July 1974.

‡ J. S. Tyler et al., "Area Navigation Systems: Present Performance and Future Requirements," Navigation: Journal of the Institute of Navigation, Summer 1975.

- **Requirement**

  Tactical MLS coverage and FAFs must be effectively interfaced with future tactical navigation systems. Acquisition of an all-altitude tactical area-navigation system will facilitate a higher level of IFR operations and place greater demands on MLS landing services during low-minima weather but would relieve MLS of providing high-minima let-down services. More study is required to identify the proper interface relationships between MLS service and various candidate area-navigation services.

O. Peacetime Army Aviation

Army aviation will operate both inside and outside the United States during peacetime. The missions will consist of routine aviation operations to transport personnel and aircraft, troop maneuvers, emergency operations for rescue, medical aid during such natural disasters as floods, blizzards, and earthquakes, and flight training for aviation proficiency.

Routine operations, troop maneuvers, and emergency missions will not be limited to VFR weather conditions. They will be flown in both the CONUS and OCONUS civil airspace and in the airspace controlled by the Army (Army airfields).

A tactical MLS configuration is required for instruction at the Army aviation school at Fort Rucker, Alabama to train new army aviators.

- **Requirement**

  Army peacetime operations will require tactical MLS avionics to operate in the CONUS and OCONUS civil airspace. Tactical MLS equipment will be required for troop maneuvers, civil emergency operations, and Army airfields.

V ASSESSMENT OF ENGINEERING REQUIREMENTS

This chapter assesses the engineering requirements for the tactical MLS configuration, FAA-ER-700-03, in terms of the operational requirements identified in the preceeding chapter.

Table 4 lists the Army operational requirements, compares them to the Engineering Requirements, FAA-ER-700-03, (Table 1), and evaluates them for compliance. Columns 2 and 3 tabulate the results of this comparison.

It was found that most Army operational requirements can be satisfied by tactical MLS configuration equipment with characteristics specified by the Engineering Requirements, FAA-ER-700-03. The operational performance of the tactical MLS at brigade-level airfields and heliports and at city heliports, however, may be degraded by multipath and ECM. Vulnerability to jamming or spoofing requires further definition.

A. Operational Performance

The purpose of the Engineering Requirements, FAA-ER-700-03, is to specify the engineering performance of the equipment aspects of the MLS tactical configuration. Performance degradation caused by the multipath environment of a tactical airfield or heliport is not considered.

The FAA-ER-700-03 specifies the equipment-performance accuracy in terms of the minimum guidance altitude under ICAO CAT-II weather condition for a split-site deployment on a 4000 or 7000 ft runway. These conditions are more representative of a corps rear airfield than brigade airfields and are not representative of a colocated deployment at a brigade or city heliport.

The degradation in performance at brigade airfields and city heliports depends on the multipath environment. The Engineering Requirements, however, do not define the operational performance to be expected in a multipath environment of such airfields or heliports. The level of degradation can be determined by constructing realistic multipath models for brigade airfields and city heliports and subjecting them to computer-modeling techniques to estimate multipath performance degradation. The physical environment must be specified in detail and all significant sources of multipath reflection must be identified.

Table 4

COMPARISON OF THE ARMY OPERATIONAL REQUIREMENTS FOR THE TACTICAL MLS CONFIGURATION TO THE ENGINEERING REQUIREMENTS, FAA-ER-700-03

Operational Requirement	Satisfied		Line Reference on Table 1
	yes	no	
Interoperability between military and civil	x		1
Volumetric coverage (5 nm, $\pm 40^{o}$ in azimuth, 2^{o} to 15^{o} in elevation)	x		2,3,5
Decision height of 100 ft for 4000 ft runway under ICAO CAT-II weather conditions			4
Rear corps airfield	x		
Rear brigade airfield and heliport		x	
City heliport airfield		x	
Landing capacity	x		none
DME capacity	x		13
Channel capacity	x		39
Operation in worldwide climate	x		34
Control of azimuth sector coverage	x		2
Control of azimuth beamwidth of elevation-angle guidance beam		x	none
Signal security		x	38
Logistics			
Mobility	x		6, 20, 16, 31
Maintenance and support	x		8, 9, 33
Interfaces	x		41
Site configuration	x		19
Integrity and executive monitor	x		18

Representative multipath propagation models for brigade airfields and city heliports are necessary to translate the equipment performance specifications to operational performance capabilities in specific environments. After obtaining estimates from these models, it will be necessary to confirm the operational performance by flight testing the MLS tactical configuration in situations representative of the Army tactical environments. Because the operational limitations of the tactical MLS configuration are determined by the multipath environment techniques that will minimize multipath interference are considered in Chapter VI.

B. Security Considerations

The Army security requirement for the landing-guidance system against spoofing and jamming is not considered to be defined adequately by the Engineering Requirements for the tactical MLS configuration.

Because the MLS will be operated in a hostile environment, the enemy is expected to exploit all possible means to reduce the effectiveness of the landing operations. To the extent that line-of-sight conditions exist, the enemy may elect to interfere or jam the tactical MLS. The engineering requirement for the airborne MLS configuration recognizes spoofing and jamming as a potential threat and states that "the MLS angle receiver/processor shall incorporate circuitry that will minimize guidance-data degradation resulting from deliberate, improper transmissions from sabotaging sources."

The FAA-ER-700-03 does not define the threat, however, and does not specify the level of protection required. This area needs further study and definition.

VI REDUCTION OF MULTIPATH INTERFERENCE

The operational performance of the tactical MLS is limited by the level of multipath interference in the tactical environment. There is little doubt that the MLS is much superior to the ILS with regard to multipath limitations, however, a brigade airfield or city heliport has a much more severe multipath environment than does a civil airport. The purpose of this section, therefore, is to consider some techniques for reducing the level of the multipath signal. Beamwidth control, signal polarization, and signal frequency will be considered.

A. Control of the Azimuth Beamwidth of the Elevation Scanning Beam

The azimuth beamwidth of the elevation scanning beam for the tactical MLS configuration is fixed at 80° to provide elevation guidance over a $\pm 40^{\circ}$ azimuth sector; however, the azimuth scan sector can be restricted to a $\pm 7.5^{\circ}$ scan to limit the azimuth service coverage. A corresponding reduction of the elevation-guidance coverage would reduce in-beam multipath interference in the elevation channel. As a result, the feasibility of a changeable elevation antenna aperture to narrow the elevation beamwidth should be considered. Possibly one of three beamwidths ($\pm 10^{\circ}$, $\pm 20^{\circ}$ and $\pm 40^{\circ}$) could be used for most tactical situations.

B. Signal Polarization

The level of the multipath signal from a vertical surface for horizontal or circular polarization is typically -10 dB below that for vertical polarization.[6] The use of horizontal or circular polarization requires that the 5-GHz aircraft antenna extend approximately 3 in. from the aircraft skin[7] which is no problem at the 100 kt airspeeds of Army aircraft. Signal polarizers will be procured as a part of the MLS Phase-III evaluation. The Engineering Requirements, FAA-ER-700-03, specify vertical polarization.

A proposed alternative is for the Army to use circularly polarized antennas for both the ground and airborne components of the tactical MLS configuration.[8] Army aircraft could then receive the vertically polarized MLS signals from civil and other military services, and the civil and other military services could receive the vertical component of the Army circular polarized tactical MLS. This would satisfy the interoperability requirement and should be evaluated during the MLS Phase-III performance testing.

C. Signal Frequency

Increasing the signal frequency of the MLS will permit a narrower beamwidth of the scanning beam antenna and a greater antenna gain for the same antenna size. The increase in signal frequency, however, will result in a greater attenuation of the signal in a rainfall and a reduction in the capture area of the aircraft antenna (assuming a quarter-wave stub antenna). These relationships are summarized below, assuming a constant power input to the scanning beam antenna.

Signal Frequency (GHz)	Antenna Beamwidth (degree)	Scanning Beam Antenna Gain (dB)	Path* Attenuation (dB)	Aircraft† Antenna (dB)	Total (dB)	Net Change (dB)
5	3	20	-6.0	0	14	0
10	1.5	23	-15	-6	2	-12
15	1	25	-30	-10	-15	-29

Here it can be seen that the system loss increase by 12 dB when the signal frequency is doubled and by 30 dB when the signal frequency is tripled. This increase must be compensated for by increased power at the MLS transmitter to obtain the same signal level at the airborne receiver. Power increases of 12 to 30 dB will require vacuum tube amplifiers and will impact directly on the operational requirement of a minimum two-hour operation with battery power.

There is a transition from specular reflection to diffuse scattering of multipath signals as the signal wavelength is decreased and becomes less than the dimensions of the surface irregularities of the reflector. Specular reflection occurs at frequencies for which the wavelength is greater than the surface irregularities. For large surfaces, the intensity of the reflected signal varies with the angle of incidence and polarization, but is independent of the signal wavelength.

Diffuse scattering occurs at frequencies for which the wavelength is less than the surface irregularities. The scattering coefficient is also a function of the angle of incidence and polarization, but varies inversely as the wavelength squared.[26]

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* 10 mile path: 5 miles at 50 mm/hr, and 5 miles at 25 mm/hr rainfall.

† Assuming a quarterwave stub antenna is used on the aircraft.

Thus, depending on the roughness of the reflector surface in terms of the signal wavelength, the angle of incidence, and the polarization the level of the multipath reflections for a particular propagation geometry may decrease with increasing signal frequency. Under the most favorable conditions the multipath level could decrease by as much as 6 dB as the signal frequency is doubled, or by as much as 9.5 dB as the signal frequency is tripled. Clearly, this possible reduction in the intensity of the multipath signal level with increasing signal frequency is dependent on the physical characteristics of the reflecting surfaces and cannot be evaluated without detailed information. Since the shapes and surface textures of possible reflecting objects vary widely, this area requires further study and investigation of materials found in typical airport environments.

It is concluded that the RF power requirements increase with increased signal frequency and that the intensity of multipath reflections may possibly decrease with increased signal frequency. However, the possible decrease in the multipath intensity is dependent upon the surface irregularities of the reflecting objects relative to the signal wavelength.

VII PHASE-III EVALUATION OF THE MLS TACTICAL CONFIGURATION

Two tactical configurations of MLS equipment are to be procured for evaluation by DOD during Phase-III of the common Microwave Landing System development. During this evaluation, representatives of the Army will be responsible for determining whether the performance of the Phase-III tactical MLS configuration satisfies the Army operational requirements for an IMC landing system. As a result, the Army will have to prepare a test plan to evaluate the effectiveness of the MLS tactical configuration in meeting the operational requirements.

The purpose of this part of the study is to identify specific factors that should be critically examined by the Army during the DOD performance evaluation.

The Engineering Requirements, FAA-ER-700-03, do not define the operational performance of the MLS tactical configuration in a multipath environment. These requirements specify that the equipment must be capable of a minimum guidance altitude of 50 ft for a 4000 ft runway and 150 ft for a 7000 ft runway, under ICAO CAT-II weather conditions, with a split-site deployment. The operational performance and limitations for split-site deployment at brigade airfields or for colocated deployment at brigade and city heliports is not specified and will have to be estimated by simulation and confirmed by flight tests during the Phase III evaluation.

A. Flight Testing for Performance Evaluation

The objectives of the flight tests are as follows.

(1) To verify that MLS Tactical Configuration equipment meet the Engineering Requirements, FAA-ER-700-03, and will provide a decision height of 50 ft and 150 ft for 4000 and 7000 ft runways under ICAO CAT-II weather conditions, with a split-site deployment.

(2) To determine the limitations of the MLS tactical configuration when installed at Army corps rear and brigade rear airfields and heliports and urban heliports.

(3) To assess the relative performance of horizontal, vertical, and circular signal polarizations.

(4) To uncover characteristics of the system that may limit the performance when installed in current and future Army helicopters (rotor modulation, aircraft speed).

(5) To evaluate the security, integrity, and logistics of the tactical MLS configuration.

The first objective is common to all military services and to the actual procurement of the tactical MLS configuration. The others are of special interest to the Army and will be discussed further.

1. Performance Limitations in a Multipath Environment

Flight tests should be conducted with both fixed-wing aircraft and helicopters to determine the performance limitations of the split-site deployment of the tactical MLS configuration. The ground equipment should be installed at several airfields representative of Army corps rear and brigade rear tactical airfields. This would include such test sites as:

- an Army Supply Depot Airfield, such as Sharpe Army Depot
- an Army Airfield, such as Fritzsche AAF, Fort Ord, California
- the Army Aviation School at Fort Rucker, Alabama

Flight tests should be made with helicopters to determine the performance limitations of colocated site deployment of the tactical MLS configuration.

The ground equipment should be installed at several sites representative of brigade and urban heliports. This would include:

- a downtown city park or parking lot
- a city hospital helipad
- a football stadium
- an Army supply depot helipad
- a pier of a typical seaport, such as the San Francisco Bay or New York harbor

A site survey is recommended, and a site description should be prepared before the final selection is made.

The flight tests should include optical tracking of the aircraft during approach, recording of the pilot's guidance display signals, and instrumentation to record the operation of the signal processor in the multipath interference.* The object is to determine the level of the multipath interference and the resulting errors in the guidance display.

The physical environment of the flight test should be well documented to permit computer modeling of the multipath environment for comparison of the measured and computer-calculated performance results. This is very important because the development of an accurate computer model will minimize the flight time required to investigate different tactical situations.

2. Advantages of Horizontal and Circular Signal Polarizations

The Army should determine the advantages to be gained by the use of horizontal or circular signal polarization. It is recommended that the flight-test measurements described above be repeated at each location with vertical, horizontal, and circular signal polarizations.

3. Rotor Modulation

Rotor modulation for the HU-1 helicopters is approximately 10 Hz which is near the average 13-Hz update rate of the azimuth guidance signal. Conceptually, the purposely added jitter in the azimuth update rate of the MLS signal format eliminates possible interference caused by propeller and rotor modulation. This should be verified during the Phase-III evaluation tests. Laboratory measurements should be made on an airborne MLS receiver with a signal modulated to simulate a 13-Hz rotor modulation frequency.† The purpose is to ensure that future helicopters need not be designed to avoid a 13-Hz rotor modulation frequency so as to be compatible with the MLS.

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* The FAA has ordered a precision-automated tracking system (PATS) from GTE Sylvania. This is a mobile laser ranging and tracking system, with angular accuracies of ± 0.1 mrad and range accuracies of ± 0.3 m, and has a provision to telemeter real-time tracking data to the aircraft. Although the equipment is mobile, it requires a concrete pad for stabilization.

† The maximum allowable rotor speed for the UH-1 helicopter is 339 rpm which corresponds to a rotor modulator frequency of 11.3 Hz. It is not possible, therefore, to produce this condition during the flight tests. An alternative to be considered is the lowering of the average update rate during the flight test so as to coincide with the rotor modulation frequency.

4. Control of Volumetric Coverage

The effectiveness of reducing multipath interference by limiting the azimuth and elevation scan sectors of the MLS configuration is very important for operation in a tactical multipath environment.

Flight-test evaluation should be made in the multipath environments, with azimuth and elevation scan sectors as the variable parameters. In particular, multipath interference in the elevation channel, resulting from a fixed azimuth beamwidth for the elevation beam should be explored; this will require provision to adjust the azimuth beamwidth of the elevation scanning beam. Methods by which this can be accomplished should be analyzed for the elevation scan antenna.

B. Related Performance Factors

Although not directly related to the flight test for performance evaluation, the following factors are significant for the deployment of the tactical MLS configuration and should be evaluated during the Phase-III testing by the Army:

- Security
- Executive Control
- Mobility
- Feasibility of Fixed-Base Operations

1. Sensitivity to Interference, Jamming, and Spoofing

The tactical MLS equipment, both ground and airborne, are expected to operate in a hostile electromagnetic environment as well as a physical one. As a result, the tactical landing system will be subjected to unintentional interference from friendly electrical and electronic equipment and to intentional interference, jamming, and spoofing by the enemy. Because the MLS equipment cannot be designed to be immune to all levels of interference and jamming, it is essential that sensitivity thresholds be established. These threshold parameters can be used for guidance in the deployment of the tactical MLS or for a basis of design change. In any event, the interference and jamming thresholds should be established early in the Phase-III evaluation.

The threshold sensitivity of the tactical MLS configuration to interference, jamming, and spoofing can be determined by laboratory measurements that should be made prior to the flight tests and on both the airborne and ground equipment. The simulation facility at

CALSPAN* should be suitable for these measurements. The interference and jamming sensitivity thresholds must be established for the UHF radio links used for synchronization of the azimuth and elevation-angle transmitters and for remote control of the tactical landing facility. Analyses of these links will be straightforward.

The susceptibility of the DME ground transponder to interference, jamming, and spoofing should also be established. This is particularly important when the system is operating in the demand mode in which a properly coded DME interrogation is required to activate the angle-guidance transmitters.

2. Executive-Control Functions of the Monitor

The purpose of the performance monitor is to ensure that the radiated guidance signals are within operating tolerance. It should also prevent the radiation of out-of-tolerance, false, or dangerous guidance signals by equipment shutdown.

This executive-control function must operate reliably over a wide range of environmental conditions typical of Army tactical operations. The equipment will be set up on mud, snow, and on other unstable supporting surface. The executive monitor will be expected to shut the equipment down if the equipment should shift or settle so as to radiate an out-of-tolerance guidance signal. Furthermore, in a split-site configuration, failure or interference with the intersite UHF radio link should not incapacitate the MLS or the executive-control function

Because of the operational significance of this executive-control action, it is recommended that consistent attention be given to the monitor performance throughout the Phase-III evaluation.

3. Mobility

Mobility is one of the most important factors in a tactical Army operation. For the tactical MLS to be of most value to the Army, it is essential that the equipment be transportable and capable of providing a reliable landing-guidance signal within 15 min after transport. Equally important is the capability to ready the equipment for transport and to move out in a similar time period.

It is believed that the time to ready the deployed MLS tactical equipment for retransport has not been emphasized. It is recommended, therefore, that, during the Phase-III evaluation, equal attention be given to the time to set up and the time to repack for transport. In

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* Calspan Corporation, Buffalo, New York.

addition, flight tests should be made immediately after a timed set-up to determine the alignment of the signal in space--without subsequent realignment or adjustment.

4. Feasibility of Extended Fixed-Base Operations

In a peacetime situation, as in Europe, a tactical Army unit may not move for months. As a result, the tactical MLS equipment may be used in essentially a fixed-base operation and will have to be maintained and serviced in the field over long periods of time. The concern is over the lack of a shelter for personnel, for keeping out water and dirt while servicing the equipment, and for preventing continued exposure of the operating controls to the weather. It is recommended that attention be focused on this aspect of maintenance during the Phase-III evaluation.

VIII MULTIPATH PROPAGATION MODELS

Five computer models for multipath propagation were reviewed to determine their suitability for investigating multipath problems related to the use of the tactical MLS configuration at Army airfields and heliports.

Three programs, the IBM,[10,11] the Ohio University,[12,13] and the TSC,[14,15] were developed to investigate ILS performance in a multipath environment. Although these three computer programs would have to be modified for the MLS, they were of interest because modeling techniques and algorithms for the multipath reflectors are common to both ILS and MLS.

Two programs, Lincoln Lab,[16-24] and Meyer Associates,[25] were specifically developed for MLS multipath analysis. The principal purpose of the Meyer Associates program is to investigate the effects of signal polarization. This program has limited capabilities in other areas as compared to the other four programs reviewed.

The area of major concern for the five models reviewed was the level of expert judgment required by the program user. The complexity of most real multipath situations is such that it is not feasible, or desirable in terms of computer size and computation time, to include all reflecting surfaces in the multipath model. The program user must decide, therefore, on the significance of each reflector in the environment relative to his particular problem. The failure to include one or more significant reflectors will result in a discrepancy between the computed and measured results. As a result, in considering multipath-model accuracy, it must first be assumed that a valid model has been used.

Generally, the multipath computer models considered are satisfactory when predicting the location of multipath interference caused by specular reflection. The accuracy of the calculated multipath signal level, however, is estimated to be in the range of ± 3 to ± 1 dB, at best, and depends on the size, shape, and material of the reflection object. The accuracy is best for large flat reflectors where geometric-optics techniques can be used and, depending on the approximations made, is poorest for irregular objects in the region of one Fresnel zone in area.

The differences among the five computer models are found to be in the algorithms for the reflecting surfaces, approximation techniques used to calculate the level of the reflected signal, program organization, and model computer employed.

Table 5 is a matrix for comparing the five multipath computer models. The first column lists the desirable program features as developed in the appendix of this report. It can be seen that the Lincoln Lab appears to satisfy most of these features; however, there are the following weak areas.

- Reflections from periodic surfaces are not considered.
- Horizontal and circular polarizations are not included.
- Buildings and hangers are modeled as rectangular perfectly conducting surfaces with a roughness factor applied to account for conductivity.
- There is limited verification of the shadowing algorithms used.
- Expert judgment is required to appropriately define the multipath environment.

Dr. J. E. Evans indicated a high level of activity in the use and further development of the Lincoln Lab multipath model. Currently, work is in progress to verify the modeling techniques by measurements at various airports. New computer algorithms are also being developed for the reflection of horizontal and circular signal polarizations.

The organization of the Lincoln Lab program is very flexible and facilitates changing reflection algorithms without major revisions of the main program. It is recommended, therefore, that the polarization algorithms developed by Meyer Associates and the algorithm for reflection from corrugated surfaces developed by Dr. Mink of ECOM be incorporated into the Lincoln Lab program. It is further recommended that multipath measurements at various airports be continued to validate and develop confidence in the multipath computer model.

Table 5

COMPARISON OF MULTIPATH PROPAGATION MODELS

	Desirable Requirements	Models				
		IBM	Ohio	TCS	Lincoln	Meyer
Program written for:	MLS	ILS	ILS (glidescope)	ILS	MLS	MLS
• Basic algorithms						
Geometric optics	x	x			x	x
Fresnel integral	x		x	x	x	x
Scattering cross section	x				x	x
Shadowing	x				x	
• Algorithm selection						
Manual		NA	NA			x
Computer	x			x	x	
• Field at receiver						
Total		x	x	x		
Multipath components	x				x	x
• Receiver-processor algorithm						
Separate program					x	
Part of multipath program		x	x	x		
No program						x
• Polarization						
Vertical	x				x	x
Horizontal	x	x	x	x		x
Circular	x					x
• Reflecting objects						
Ground and water surfaces	x	x	x	x	x	x
Buildings	x	x		x	x	x
Aircraft	x	x			x	x
Hills	x	x	x			
Power lines	x	x				
• Number of objects	10	Unlimited	ground surface	Unlimited	Unlimited	
• Number of paths	4	2	2	4	4	
• Reflection surfaces						
Snow	x		x			x
Smooth	x		x	x	x	x
Perfectly conducting	x	x		x	x	x
Small-scale rough	x				x	
Very rough	x		x		x	
Imperfect dielectric	x	x	x		x	
Periodic	x					x
• Transmitter antenna pattern				x	x	x
• Receiver antenna pattern	x	x		x	x	x
• Flight profile						
Straight approach	x		x	x	x	x
Fly-by	x				x	
Orbit	x			x		
• Program organization						
Executive with modular subprograms	x	x	x	x	x	
• Input data format						
Manual						x
Punched cards	x	x	x	x	x	
Interactive terminal	x				x	
Graphic display for editing	x				x	x
• Output data format						
Graphics	x	x		x	x	x
Page print	x	x	x	x	x	x
Magnetic tape	x				x	x
• Computer type	IBM-370	IBM-360 Model 40	IBM-7090 IBM-1620	PDP-10	IBM-370	HP-9820
• Computer language						
Fortran	x	x	x	x	x	
Basic						x
• Estimated accuracy of multipath relative to direct path	$\pm\frac{1}{3}$ dB	?	?	?	±1 dB (estimate)	±1 dB (estimate)
• Estimated accuracy of diffuse scattered field	±5 dB					
• Typical running time		10-15 min	2.4 min/pt on IBM-7090 4 hrs per point on the IBM-162D	?	1-2 min	?

IX CONCLUSIONS AND RECOMMENDATIONS

- The Army requires the deployment of a tactical MLS configuration to handle the expected increase in Army IMC flight activity during the 1980-1990 era. The Army also requires MLS tactical avionics so as to be interoperable with civil and other military services.

- The Army tactical MLS configuration will be deployed at rear corps and rear division airfields, brigade heliports, and at fixed Army bases. The tactical MLS configuration will not be deployed forward of the brigade area.

- The Army tactical MLS configuration will be deployed as a close-split site for special helicopter missions such as medevac in urban environments and at brigade heliports.

- The Army Operational Requirements, as revised October 1973, have been considered in the Engineering Requirements, FAA-ER-700-03, for the tactical MLS configuration. Neither the Army nor the engineering requirements, however, specify the guidance accuracy necessary in multipath environments such as brigade airfields and heliports and urban heliports. It is concluded, therefore, that the Engineering Requirements do not ensure that the tactical MLS configuration guidance performance will be met at brigade airfields or urban heliports.

- It is recommended that the Army flight test of the Phase-III MLS tactical configuration hardware be conducted in a multipath environment similar to that of a brigade airfield and heliport and an urban heliport to evaluate the performance and limitations of the MLS in Army tactical situations.

- It is recommended that the following techniques for the reduction of multipath interference be evaluated during the Phase-III flight test:

    - Control of the azimuth beamwidth of the vertical scanning beam.

    - Use of horizontal or circular signal polarization.

- It is recommended that the following logistics and system integrity factors be evaluated by the Army during the Phase-III testing of the tactical MLS:

    - Operation and reliability of the monitor and executive control.

    - Feasibility of fixed-base operations over extended periods of time.

    - Ground system mobility--time to set up and time to ready for retransport.

- The Engineering Requirements for security considerations do not satisfy the Army Operational Requirements because the threat and level of security required have not been defined. It is recommended that further study and definition be given to security and that deployment criteria be developed to minimize line-of-sight exposure to enemy electronic signals.

- It is recommended that analyses and laboratory measurements be made prior to flight testing to determine the sensitivity of the MLS avionics and ground equipment to interference, jamming, and spoofing.

- The landing rate is limited by runway capacity and the separation of aircraft to minimize collision and not by the engineering characteristics of the tactical MLS configuration.

- A 200-channel capacity is required for interoperability with civil airports and aircraft in limited warfare and emergency situations.

- It is concluded that the RF power requirements for the MLS transmitter rapidly increases with signal frequency; however, the level of the multipath interference may decrease because of the possible transition from specular reflection to defuse scattering as the signal wavelength decreases. Because of the wide range of materials and surface textures found in an airport environment, it is recommended that further study and investigation be made to quantify the possible reduction in multipath intensity as a function of signal frequency.

- The Lincoln Lab MLS propagation computer model, currently in use and undergoing refinements, can be used to investigate the Army multipath propagation environments; however, a detailed and valid description of the physical environments of corps and division airfields and heliports is required. It is recommended that this computer program be modified to include algorithms for horizontal and circular polarizations and corrugated surfaces.

- It is recommended that the Lincoln Lab MLS multipath computer model be used to calculate the tactical MLS configuration performance in multipath environments similar to brigade airfields and heliports and urban heliports. The objective is to compare the measured and calculated performances so as to develop confidence in the computer model.

Appendix

MULTIPATH PROPAGATION MODELS

Experience with the ILS has indicated that the operational performance in a real-world environment is degraded from that estimated for the system concept model. This degradation is largely the result of reflections of the radiated guidance signal from terrain, buildings, and other aircraft. These reflections, or multiple propagation paths (multipath), limit the service category of the landing facility.

Because multipath effects are environment or site dependent, it is very desirable to develop a technique for modeling the site. The availability of a computer model will facilitate the evaluations of new guidance techniques, potential sites before an installation is established, and proposed environmental changes to existing sites.

The purpose of this Appendix is to consider the requirements for a multipath MLS propagation model and to evaluate the potential of five selected computer models to satisfy these requirements.

A. Definition of the Problem

The radio-frequency energy radiated from the landing facility will illuminate other objects in addition to the user aircraft. Depending on the size, shape, and surface material of the objects, energy will be reradiated and may reach the user aircraft by paths other than the direct or line-of-sight path. Because these multipath signals must travel a greater distance, they are delayed in time relative to the direct signal and thus distort the amplitude and pulse shape of the received guidance signal. Furthermore, in the scanning-beam landing system, multipath signals may be received when the scanning antenna is pointed toward a reflector, thereby, producing ambiguous angle information.

The magnitude of the guidance error caused by multipath signal distortion depends largely on the relative signal strength of the desired direct signal to the sum of all the undesired multipath signals. The error also depends on the characteristics of the guidance signal processor used in the aircraft.

The problem is to model the scanning-beam MLS signal received at the aircraft as a function of aircraft position in the service volume, including the effects of multipath reflection from objects of various size, shape, and material that constitute the propagation environment. The problem should also include a model of the airborne receiver, or angle processor, to estimate the angular errors resulting from the multipath environment. Although the angle processor is considered to be outside the scope of this study, it should be discussed briefly because it determines the accuracy of the multipath model required for a realistic estimate of MLS performance.

B. MLS Propagation-Model Considerations

1. Required Accuracy

The usefulness of a computerized multipath propagation model to estimate the performance of the MLS in a multipath environment depends to a large extent on the degree of confidence, or accuracy, in the estimated multipath signal level relative to the direct-path signal level. The accuracy requirement is related to the characteristics of the airborne MLS angle processor and is believed to be on the order of ±1/2 dB to obtain meaningful estimates of the MLS performance when the multipath signal level is within 6 dB of the direct-path signal level. To investigate the effects of signal polarization, this accuracy is required for vertical, horizontal, and circular polarizations in addition to smooth periodic reflecting surfaces usually characteristic of an airfield environment.

A detailed discussion of the airborne angle processor is outside the scope of this study; however, a significant difference between the ILS and MLS signal processor should be recognized. The ILS signal format is such that the differential depth of modulation (DDM) of the 90 and 150 Hz tones is directly related to the deviation from the approach path. The ILS airborne processor can be modeled, therefore, as a linear transformation from DDM to the CDI current. Errors caused by multipath are related directly to the DDM under multipath conditions, and little can be done in the signal processor to reduce these errors.

The MLS uses a time-ordered signal format in which angular information is derived in the aircraft from the time between the TO and FRO scan of a narrow guidance beam; thus, multipath signals may arrive at a different time and with a different amplitude than the direct-path signal. As a result, the MLS signal processor can use time and amplitude to provide a measure of discrimination against multipath and thereby reduce the multipath angle errors.

The timing between beam scans is determined in the aircraft on the bases of the signal amplitude referenced to a threshold set 4 dB below the maximum received-signal level. Multipath signals arriving within the 150 μsec period of the beam sweep past the aircraft may distort the pulseshape so as to shift the 4 dB threshold crossing. Multipath signal levels -1 to -6 dB below the maximum received-signal level are most likely to contribute to a mean error in the indicated angle.[15] Multipath signals well below the -4 dB threshold (-20 to -30 dB) will cause noise-like interference at the threshold crossing that will increase the dispersion of the error but will not generate a significant mean error. Multipath signal amplitudes that are within -1 to -6 dB of the direct-path signal are of the most concern, therefore, in estimating the performance of the MLS in service multipath environment. To obtain useful results within this 5 dB range, it is desirable that the multipath signal be estimated with a confidence of ±0.5 dB.

2. Input-Data Format

For ease of operation and to minimize the need for highly skilled personnel, the data input to the computer should be limited to a physical description of the propagation environment in terms of dimensions, material, and location of the reflectors relative to the MLS facility and the aircraft. It should not be necessary for the program user to evaluate each reflector and to decide which reflector algorithm is to be used.

Other parameters, such as polarization, signal frequency, beamwidth, and aircraft antenna patterns, also must be entered. For ease of operation, there should be provisions to enter data from punch cards, or from an interactive computer terminal programmed to ask the operator for the data required. It is also very desirable to display the input data as a plot plan of the airport before the program is executed. This reduces the possibility of errors in describing the location of reflecting objects to be considered.

3. The Output Data Format

The program output should be in a readily usable form such as graphic plots as a function of aircraft position on the approach path. It is desirable, however, to store the output data on magnetic tape so that they can be used with various computer models of the angle processor without the need to rerun the multipath model.

4. Program Organization

The organization of the computer program is important because it determines the adaptability of the program to different multipath situations and, to a large extent, the computer size and time required to run the program.

It is also desirable that the program for the airborne angle processor be separate from the multipath program because the angle-processor logic may vary as new techniques are developed. Provisions to store the multipath program output on magnetic tape will facilitate the development of new angle-processor algorithms without the need to rerun the multipath program.

The program language, computer size, running time, and output-data format are of practical interest because these factors determine the computer facility and time required to use the program.

C. Multipath Modeling Techniques

Geometric optics can be used to obtain a first-order approximation of the multipath signal level arriving at the receiver. In most cases, this technique will identify the regions of specular reflection but will not give the correct multipath signal level unless the reflecting object is a very large flat sheet.

Simple geometric optics do not consider scattering from rough surfaces or multiple specular reflection from periodic surfaces such as a corrugated metal sheet. The geometric-optics model also does not apply to such objects as aircraft and other small structures frequently found in an airport environment. Depending on the physical description and the electrical characteristics of the reflecting object, therefore, other techniques or models are used to calculate the level of the reflected signal. The sophistication of the modeling technique is based on the selection or development of a reflector model that can be numerically evaluated without excessive computer time.

1. Parameters and Basic Algorithms

Many factors must be taken into account in modeling multipath. Obstacles must be specified in terms of their size, shape, location, and electrical properties. Terrain and flight profiles must be considered, and receiver characteristics must be specified. Table A-1 lists the significant technical factors involved, plus the obstacle features and operating environments that relate directly to them.

It is apparent from Table A-1 that the choice of modeling technique is dependent on the size, shape, and location of the obstacle in addition to the operating frequency and polarization. At frequencies of 5 GHz and above, the obstacles normally encountered in the landing-system environment can range in size from a small fraction of one Fresnel zone to several Fresnel zones at the distances involved. When the obstacle is a small fraction of a Fresnel zone, the amplitude of the signal scattered toward the receiver can be calculated by using radar backscattering cross-section techniques. This is an important simplification for the numerical evaluation of the reflection. When the obstacle size is on the order of one Fresnel zone, a method of summation involving contributions from several small cells (Fresnel integral) must be used for accurate results; this is referred to as the Fresnel-diffraction technique and, depending on the approximation mode, requires considerable computation time.

Table A-1

Technical Factors in Multipath Propagation Models

Technical Factors	Applicable Features: Obstacle					Applicable Features: Environment				
	No. of Objects	Size	Shape	Location	Surface Features	Terrain	Flight Profile	Antennas	Data Processor	Wavelength
Basic technique used:										
Geometric optics		x	x	x						x
Fresnel diffraction		x	x	x						x
Scattering cross-section		x	x	x						x
Polarization effects				x	x	x		x		x
Reflection					x	x				x
Roughness					x	x				x
Phase shift (at obstacle)				x	x	x				x
Shadowing		x	x	x		x	x			x
Diffuse scattering		x	x		x	x	x			x
Number of echo paths	x					x				
Path loss				x			x			
Path phase shift				x			x			x
Total field at receiver	x								x	x

If the obstacle extends over several Fresnel zones, geometric-optic techniques can be used to calculate the reflected signal. This is also an important simplification because it greatly reduces numerical computation. Most objects of interest (such as aircraft), however, require the Fresnel defraction technique. In addition, the shape of the aircraft is often approximated by an equivalent cylinder or flat plate, depending on the aspect, to reduce both the computer time and the physical description of the aircraft that must be stored in the computer.

2. Other Considerations

a. The Reflector Model

Although the Fresnel integral for the amplitude of the reflected signal is considered to be a more exact technique, it requires considerable computer time, and the calculations are subject to error caused by:

- Uncertainties in defining the Fresnel-zone illumination of the obstacle
- Uncertainties in the amplitude and phase of the transmitting-antenna radiation pattern at close range to the reflecting object
- Evaluation of the Fresnel integrals without including the transmitting-antenna radiation function within the integral (a simplification made to facilitate numerical computation)
- Assumptions regarding surface roughness
- Failure to accurately describe periodic surfaces

A Fresnel-integral solution requires considerably more computation time than does the geometric-optics or radar cross-section approximations. Depending on the computer program, the decision to use the Fresnel integral or one of the faster approximations can be made by tests in the computer program or by the operator before the program is run. In the latter case, considerable judgment or expertise must be exercised by the operator; however, in the former case, the program user is wholly dependent on the skill of the programmer in developing the test criteria.

b. Reflection Roughness and Phase

For accurate results from computations using specular reflections, the dielectric constant and conductivity of the surface material must be known. From these properties of the material, the complex dielectric constant and reflection coefficient can be calculated as

$$\epsilon_R' = \epsilon_r - j\left(\frac{\sigma}{\omega\epsilon_o}\right) \qquad \text{(A-1)}$$

for the complex dielectric constant, and

$$R_v = \frac{\epsilon_R' \sin\psi - \sqrt{\epsilon_R' - \cos^2\psi}}{\epsilon_R' \sin\psi + \sqrt{\epsilon_R' - \cos^2\psi}} \qquad \text{(A-2)}$$

$$R_H = \frac{\sin\psi - \sqrt{\epsilon_R' - \cos^2\psi}}{\sin\psi + \sqrt{\epsilon_R' - \cos^2\psi}} \qquad \text{(A-3)}$$

for the reflection coefficients for perpendicular and parallel polarizations, respectively. When the reflecting surface is horizontal, these correspond to vertical and horizontal polarizations; when the reflecting surface is vertical, such as the side of a building, Eq. (A-2) applies to vertical polarization and Eq. (A-3) applies to horizontal polarization. As a result, the Brewster angle normally associated with the reflections of vertical polarization from a horizontal surface is now associated with the reflection of horizontal polarization from a vertical surface.

At frequencies of 5 GHz and higher, the imaginary part of ϵ_R' is nearly zero for all normal values of reflector conductivity; the reflection factors R_V and R_H then take on real values at all angles of incidence. The phase shift on reflection is always either 180^o or 0^o, depending on the polarization and angle of incidence. For specular reflection from smooth surfaces, therefore, calculated phase shifts will have a high degree of confidence when geometric optics is applicable. For calculations requiring Fresnel-zone summations, only approximate values of phase shift can be estimated.

For rough scattering surfaces, the phase shift on reflection cannot be accurately determined. The effect of roughness on amplitude can be accounted for, however, by a roughness factor applied to the calculated reflected amplitude.

c. Periodic Surfaces

Periodic surfaces, such as corrugated metal sheets, frequently appear on large structures (such as hangers) located on and near airfields. The reflection properties of these surfaces are dependent on the spacing and depth of the corrugations, relative to the signal wavelength and polarization and to the angle of incidence. These surfaces characteristically have more than one angle of reflection and are important because the level of the reflected signal can, depending on the number of angles of reflection, approach within a few dB of the level for specular reflection.[26]

Because of the frequent use of corrugated construction material in an airfield environment, these surfaces should be included in the multipath propagation model.

d. Polarization

The multipath computer model should specify vertical, horizontal, or circular polarization. For circular polarization, the model should be able to calculate the vertical and horizontal components of the signal at the receiver when circular polarization is transmitted.

e. Diffuse Scattering

Scattering from very rough surfaces can be classified as diffuse and characterized by random amplitude and incoherent phase. Computer calculations[16] have indicated that diffuse scattering from rough ground can be expected to be at least 35 dB below the direct signal. Because of this low multipath/direct-path ratio relative to allowable MLS margins, the calculated effects of diffuse scattering need not be included in multipath computer models. However, roughness becomes less important for small angles of incidence and specular reflection may occur for near grazing angles.

f. Multiple Paths

A sizable number of propagation paths can exist in the typical airfield environment. Reflections can stem from buildings, towers, hills, other aircraft, ground vehicles, and the ground itself. The ground applies not only to the direct signal between the transmitter and receiver, but to all other paths. For example, multipath signals from only one building would consist of four paths:

- Transmitter to obstacle to receiver
- Transmitter to ground to obstacle to receiver
- Transmitter to obstacle to ground to receiver
- Transmitter to ground to obstacle to ground to receiver

These paths must be considered in any realistic model of the MLS signal environment. It is evident that the total number of multipath components present can be very sizable, even in a relatively uncluttered environment. The extent to which these multipath signals combine at the receiver input depends on the path geometry and flight profile. The path geometry changes as the aircraft flies through the MLS service volume. Thus many itterations of the multipath computer program are required for each flight profile.

g. Path Loss and Phase Shift

To complete the estimation of the multipath signal, the additional propagation loss and phase shift relative to that of the direct wave must be calculated. This can be accomplished after the geometry is established by applying the relative attenuation,

$$\alpha = 20 \log \frac{R_R}{R_D} \qquad \text{(dB)}$$

and the relative phase shift,

$$\varphi = (R_D - R_R) \frac{2\pi}{\lambda} \qquad \text{(rad)}$$

where R_D is the pathlength of the direct wave, R_R is the total pathlength of the multipath echo, and λ is the signal wavelength.

The signal wavelength at 5 GHz is 0.06 meters; therefore, for the path phase to be meaningful, it is necessary to know the pathlengths to much less than 0.06 m. Because it is unlikely that the dimensions of the propagation environment are known to this precision, worst-case conditions are usually assumed (the multipath is in phase or out of phase with the direct signal).

h. Field at Receiver

Many multipath components may be present at the airborne-receiver terminals. The computation of the resultent signal at a point in space will be complicated by the uncertainties in the relative phases of these components. The behavior of the receiving antenna and the angle processor also must be specified to obtain meaningful conclusions concerning MLS performance. Because of the complexities involved and the need to know the component values separately to identify individual obstacle effects, it appears that summation and processing should be treated in a separate computer program. This will permit different field summation and angle-processor algorithms to be evaluated without rerunning the multipath program.

D. Comparison of Some Multipath Computer Models

Five computer models for multipath propagation were analyzed to determine their suitability for investigating MLS multipath problems. Three programs, the IBM, Ohio University, and the TSC, were developed to investigate ILS performance in a multipath environment. Although these three computer models would have to be modified for MLS use, they are of interest because modeling of the multipath reflector is common to both the ILS and MLS.

Two programs, Lincoln Lab and Meyer Associates, were specifically developed for MLS multipath analysis. The purpose of the Meyer program was to investigate the effects of signal polarization on the multipath signal level. The Lincoln Lab multipath computer program was found to be the most suitable for investigating the MLS multipath environment.

In all five programs, there is always the questions of modeling accuracy. Unfortunately, there is no exact solution for most multipath problems and, as a result, several approximation techniques must be used. Consequently, the only way to verify the modeling accuracy is to compare the computed results to real-world data; however, limitations in computer size or available computer time generally restrict the computer model to a few selected reflectors. As a result, considerable care must be taken to ensure agreement between the computer model and the measured real propagation environment.

E. Conclusions

- The Lincoln Lab multipath computer program is being used to model multipath propagation environments for MLS performance estimates. Its organization is very flexible, and subprograms algorithms for reflecting objects and airborne receivers can be changed with minimum programming effort. As a result, it can be modified to include algorithms for horizontal and circular signal polarizations and for reflections from periodic surfaces.

- The Meyer Associates multipath model consists of algorithms for calculating reflections from surfaces and objects as a function of signal polarization. This program is run on a desktop programmable calculator (HP-9820) and, at present, is not suitable for investigating complex airport environments. It is concluded that it will require a considerable programming effort to provide the Meyer Associates model with a capability comparable to the existing Lincoln Lab model. Its algorithms are of interest, however, and consideration should be given to including them in the Lincoln Lab model.

- The programming effort required to change the IBM, Ohio University, or TSC ILS models to an MLS model with a capability equivalent to the Lincoln Lab model would be excessive. Because these programs were developed for horizontal signal polarization near 100 MHz signal frequency, all of the algorithms and assumptions would have to be carefully reviewed to ensure their validity for the MLS.

- Finite computer size and processing time limit the number of multipath reflectors that can be modeled for a particular environment. The program user must therefore make value judgments when defining the computer program. The sensitivity of the calculated results to a particular reflecting object can be tested by running the computer program with and without the object; however, this does not ensure that all objects have been included. A potential source of error in calculating the multipath level is always the possibility of omission of a significant reflector in the environment.

- The estimated accuracy of a multipath signal level, relative to the direct-path signal level, was not determined in any of the five computer models. Inspection of reports describing the ILS indicates that the accuracy is probably on the order of ± 3 dB. Pending further analysis or validation by measurement, it is concluded that the accuracy of the calculated multipath signal level, relative to the direct-path signal level, is on the order of ± 3 to 1 dB at best.

- Supporting laboratory and field-measurement data are required to validate the accuracy of the multipath propagation models. These data must be collected under controlled and documented conditions so that a valid comparison can be made between the computer calculations and the measured data.

The data are needed in the following areas.

  - Measurement of relative direct and multipath signal levels for civil airports and for environments similar to an Army tactical airfield or heliport. If possible, measure the level of the individual multipath components in addition to the total multipath signal; these measurements should be made under different climatic conditions.

- Field measurements of ground reflections in which the level of the diffuse and specular components are identified separately.

- Field measurements of the effects of shadowing and defraction for propagation paths near the edges of building structures.

- Field measurements of reflection coefficients for various building configurations and construction materials, with special emphasis on propagation geometry and the number of Fresnel zones illuminating the reflection surface.

- Further laboratory measurements of the reflection coefficient for irregular and periodic surfaces as a function of polarization angle of incidence and frequency.

- Laboratory measurements of the reflection coefficient for discontinuous surface materials as a function of material shape and area, angle of incidence, and frequency.

- Field and laboratory measurements of the scattering level from various aircraft as a function of aspect angle, polarization, and frequency.

- Field measurements of the range of reflection coefficients for surface vegetation as a function of the type of plant, season of the year, signal polarization, angle of incidence, and frequency.

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